SAND2016-4549R

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Photos placed in horizontal position with even amount of white space between photos and header

Summary of Fe opacity measurement platform

- What we do, what we know, and limitations -

Taisuke Nagayama

4/14/2016

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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We heat and backlight FeMg foil using dynamic hohlraum and measure Fe opacity at T_e=150-200 eV and n_e=7-40x10^{21} cm^{-3}

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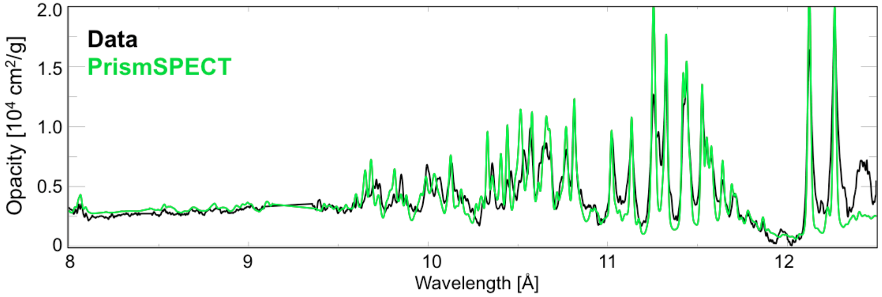
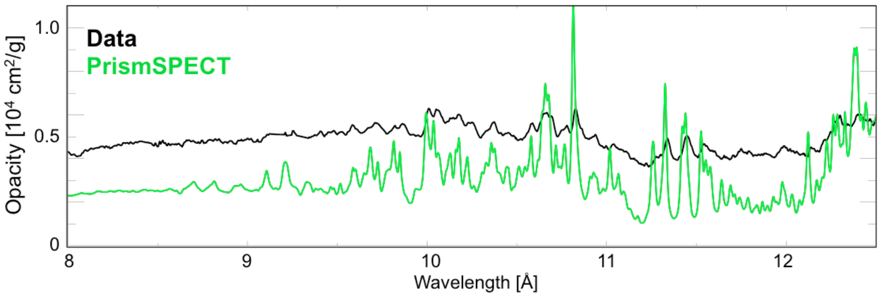
T_e = 160 eV, n_e = 7x10^{21} cm^{-3}



T_e = 195 eV, n_e = 40x10^{21} cm^{-3}



- How does the experiment work?
- What do we know from measurements?
- What do we know from simulations?
- What are the limitations?

Experiments

ZPDH opacity science platform satisfies challenging requirements for reliable opacity measurements

Z-pinch dynamic hohlraum

<u>Requirements:</u>

- Heat Fe to uniform conditions
  → Powerful ZPDH radiation
- Measure Fe conditions independently
  → Mg K-shell spectroscopy
- Deal with Fe self-emission
  → 350 eV Planckian at stagnation
- Measure transmission spectra accurately
  → Convex KAP spectrometer with x-ray films

Bailey et al PoP 2009

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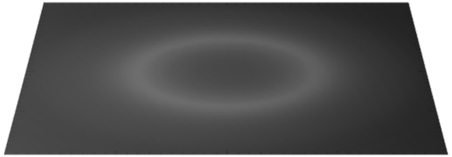

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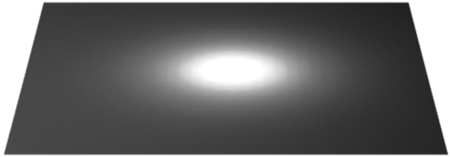

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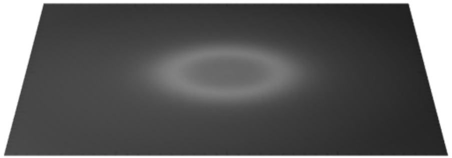
Half-moon sample



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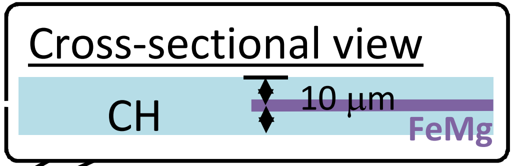

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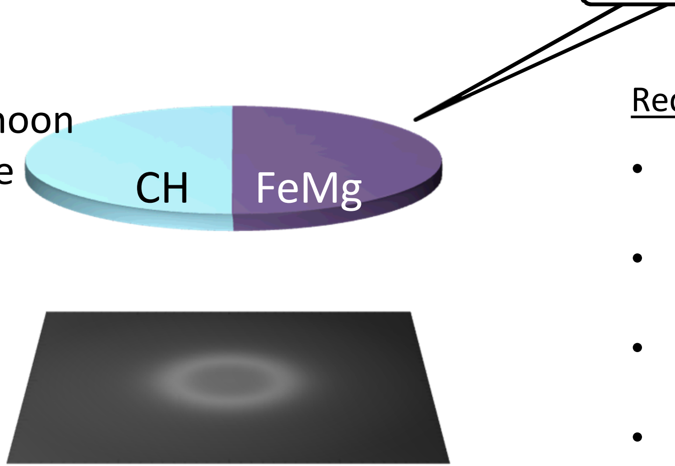

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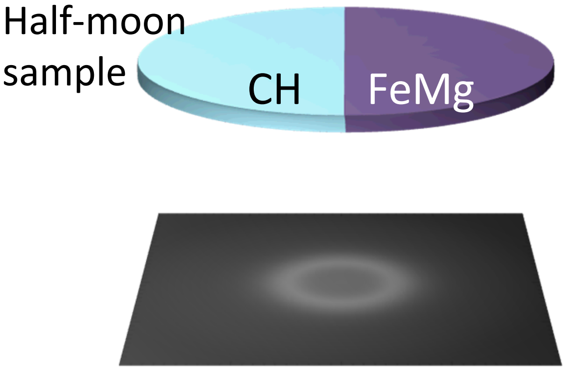

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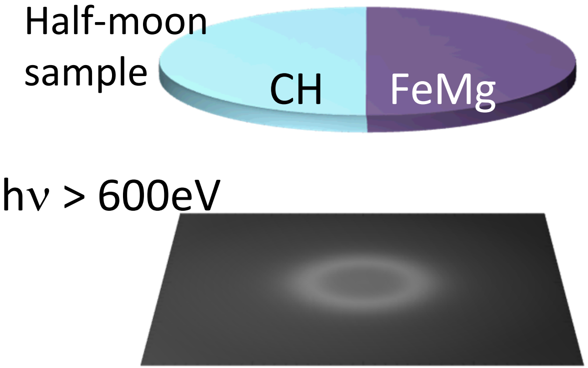

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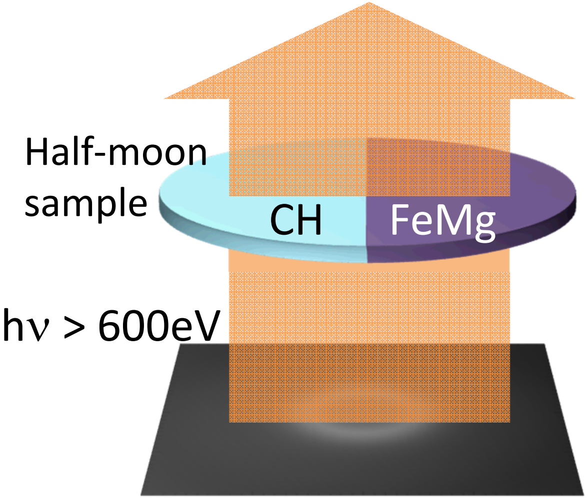

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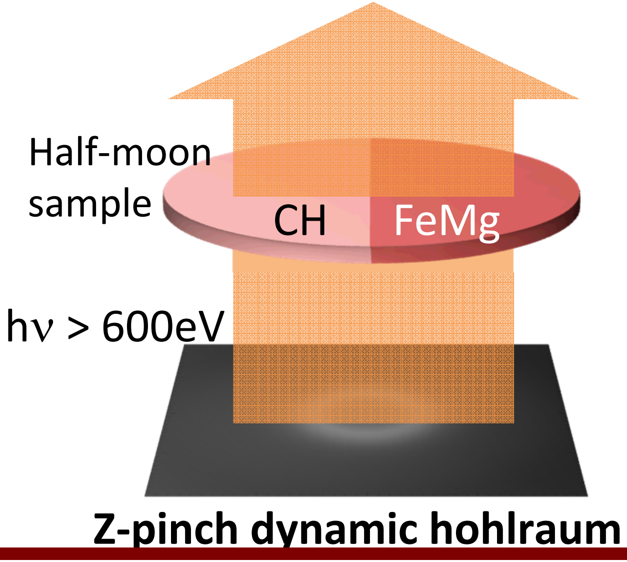

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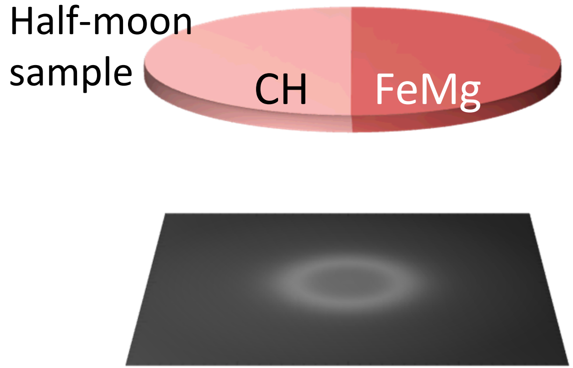

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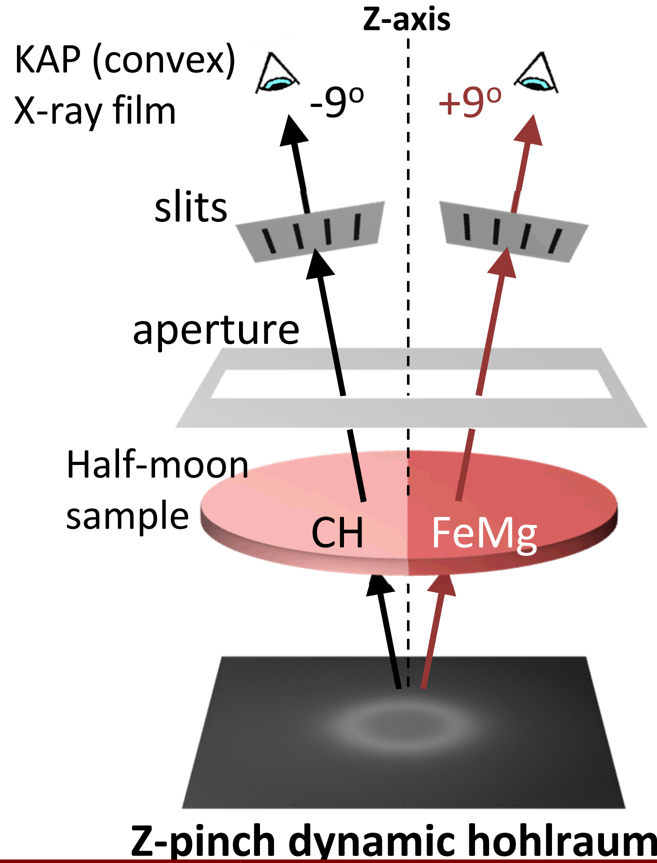

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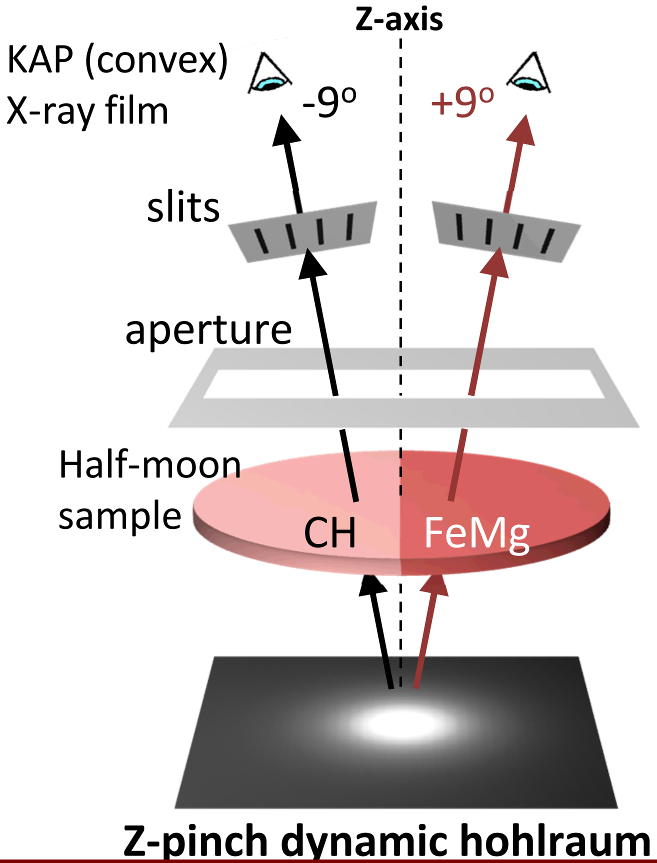

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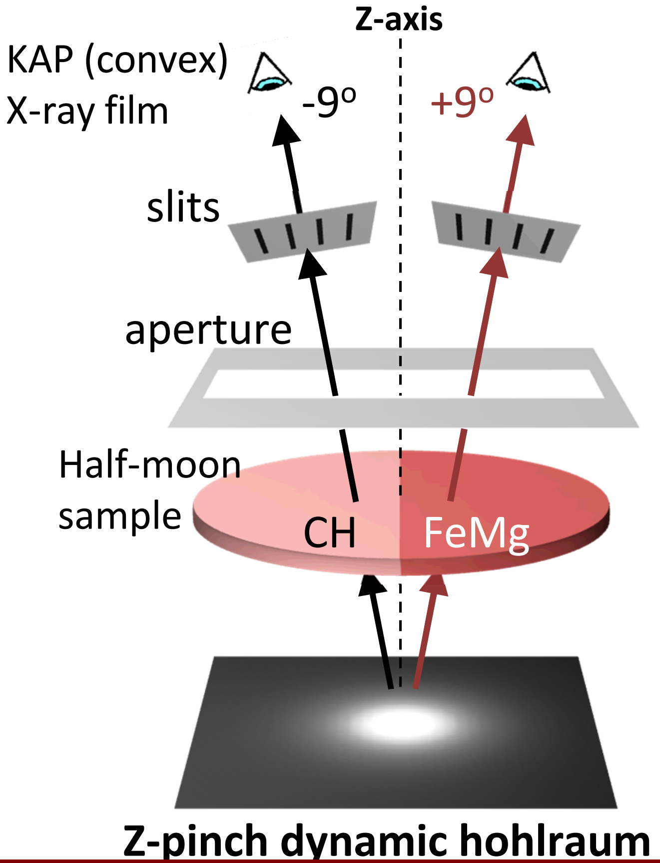

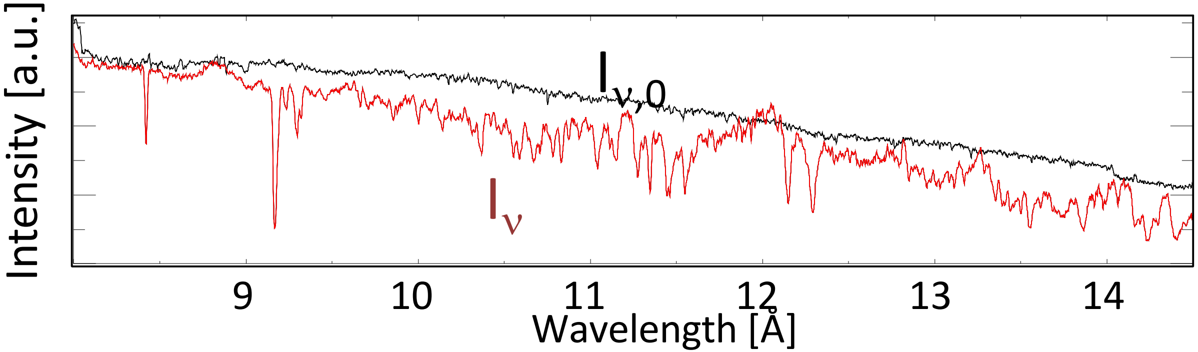

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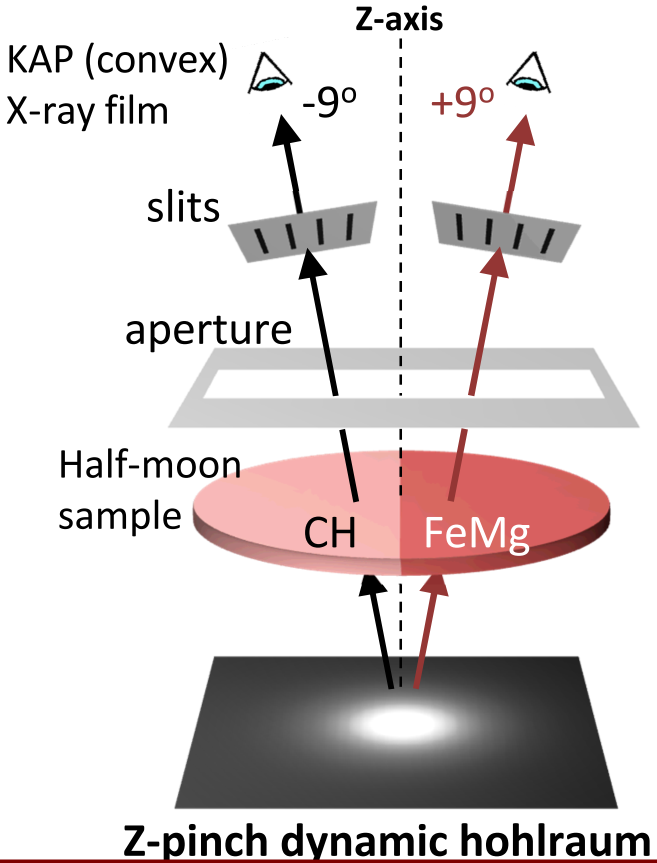

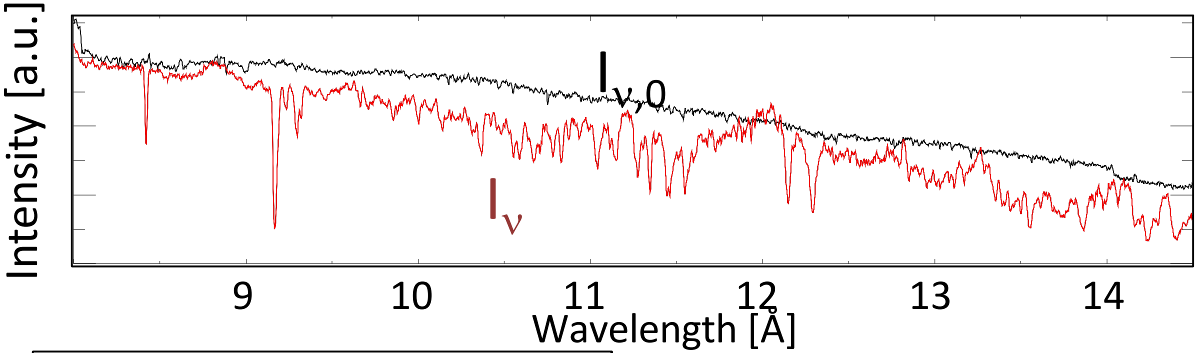

Transmission: $T_\nu = I_\nu / I_{\nu,0}$

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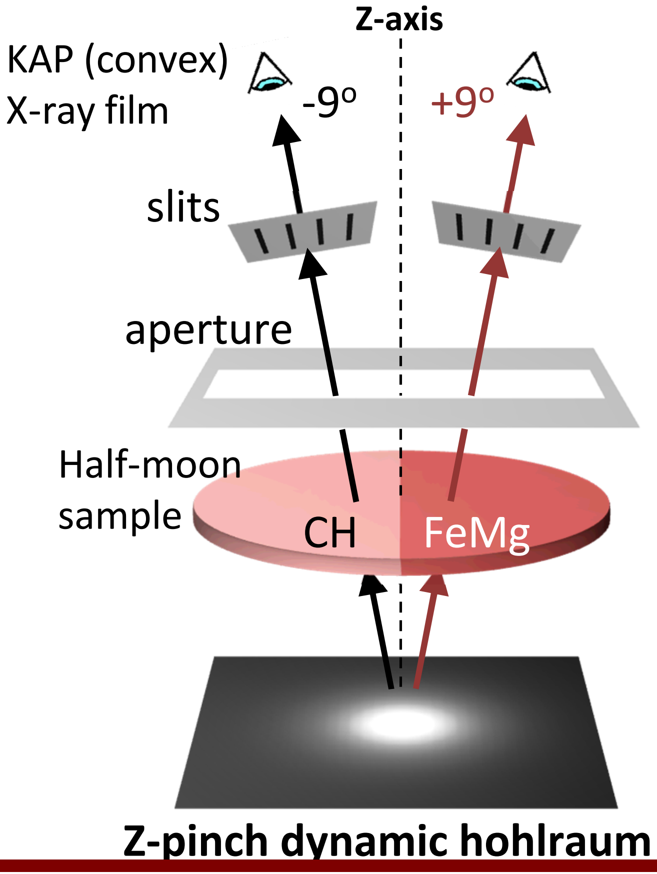

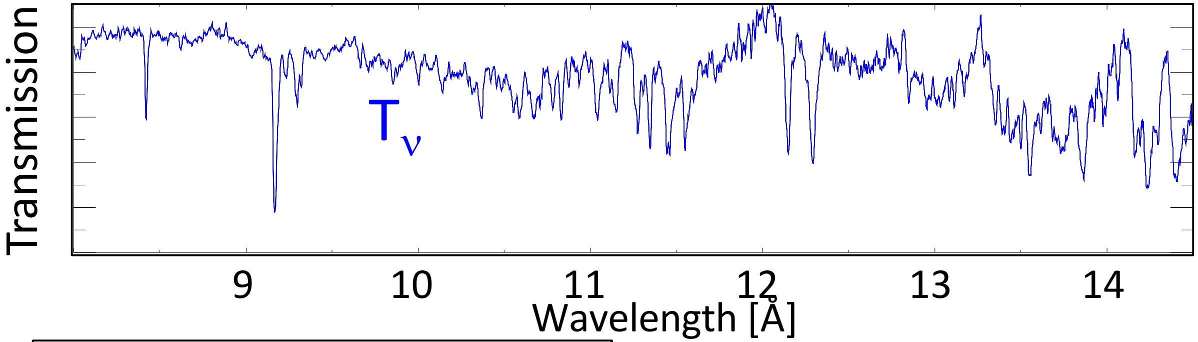

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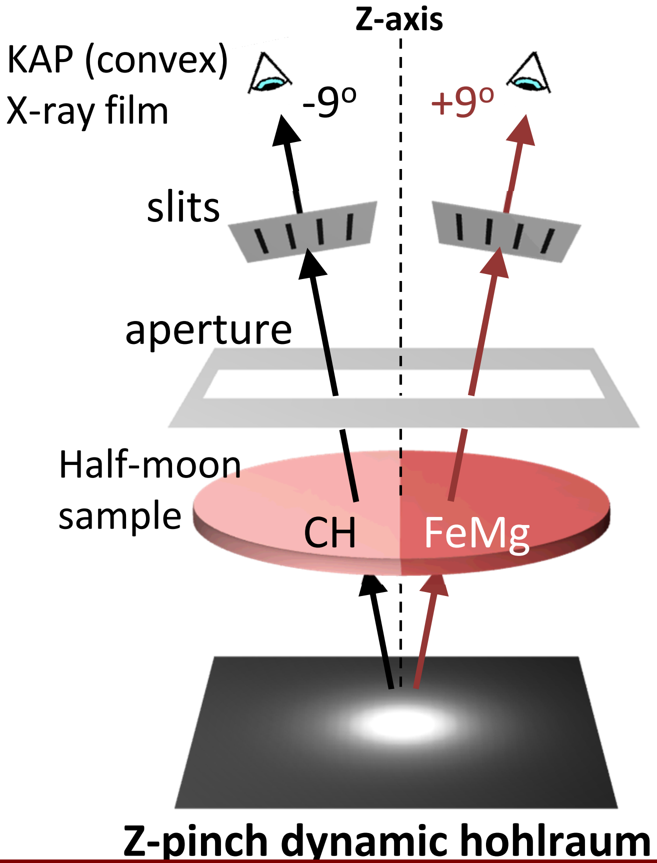

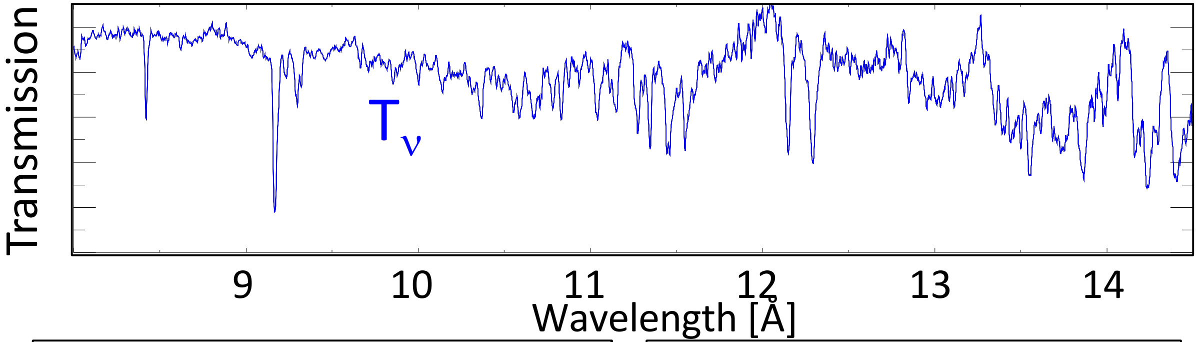

Transmission: $T_\nu = I_\nu / I_{\nu,0}$

Opacity: $\kappa_\nu = -\ln(T_\nu)/\rho L$

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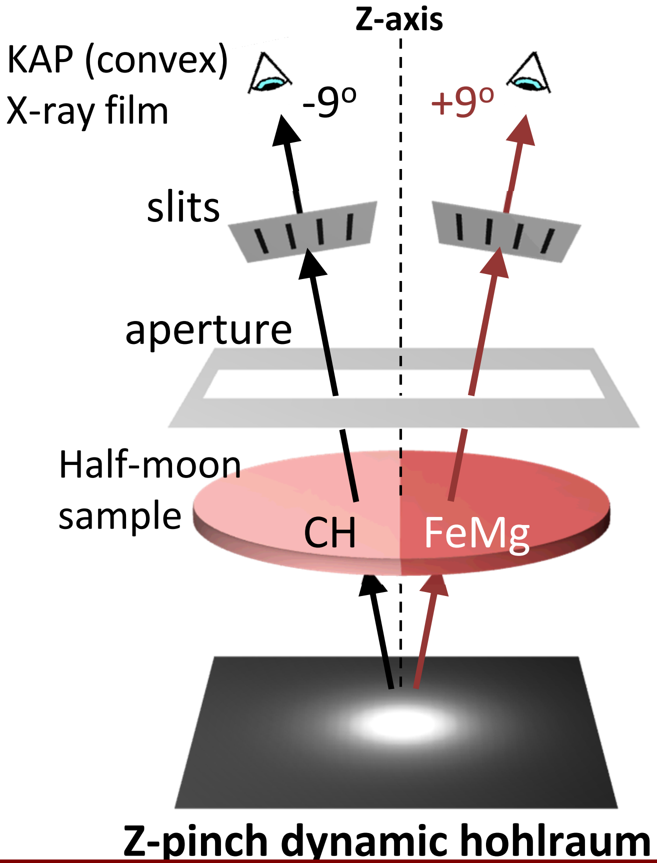

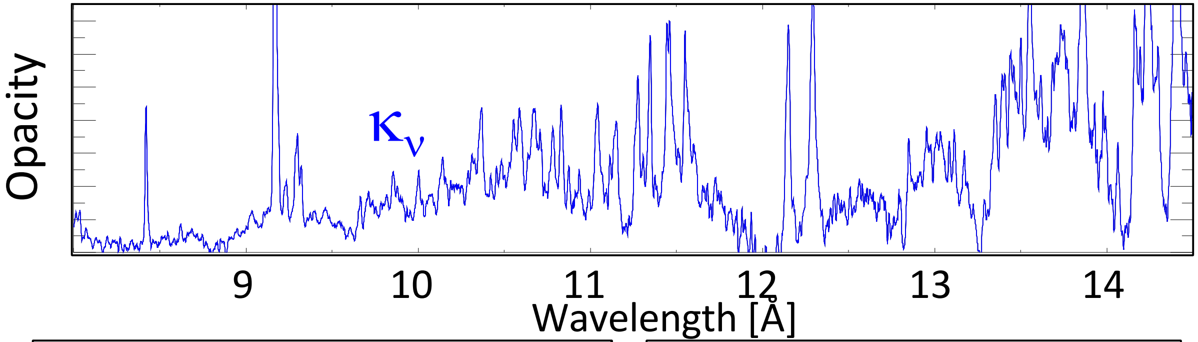

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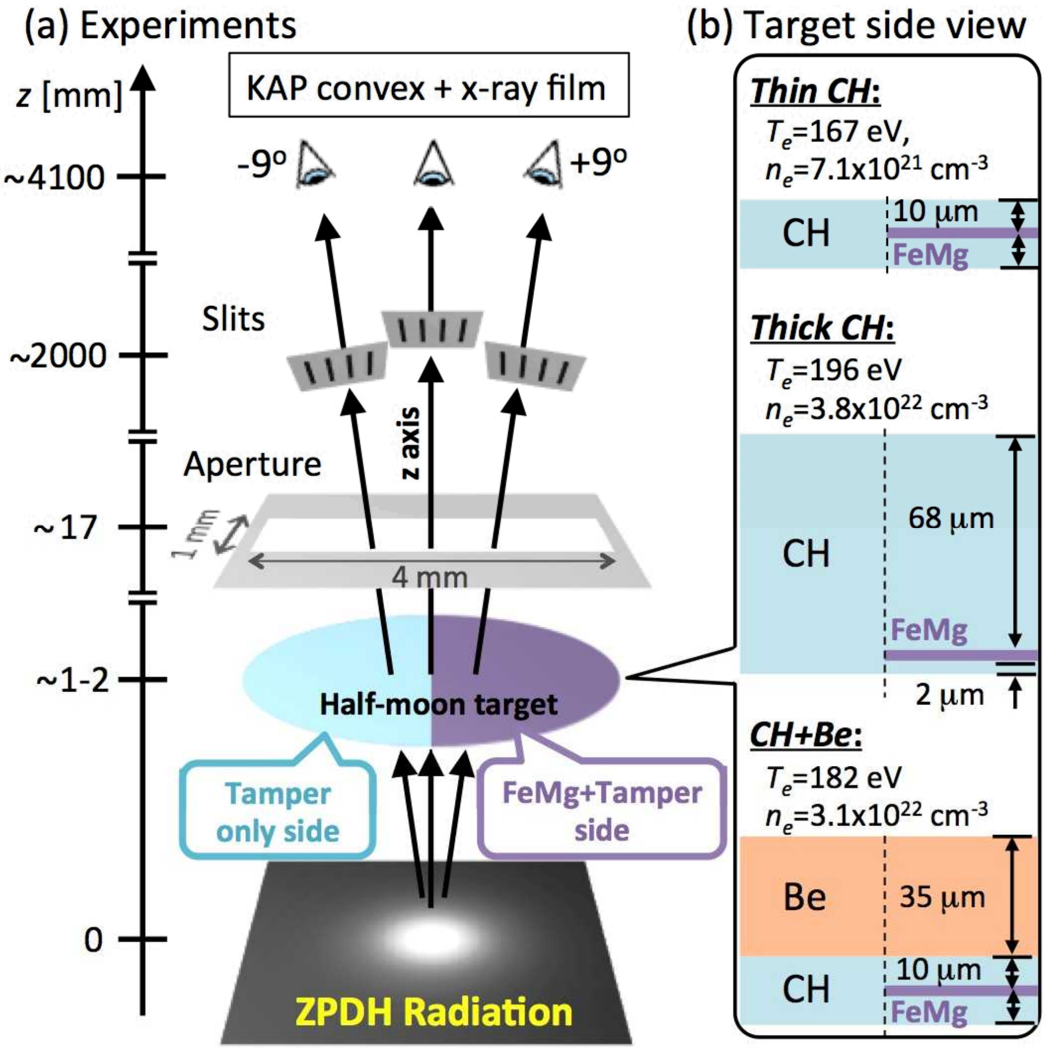

(a) Experiments
(b) Target side view
z [mm]
KAP convex + x-ray film
-9°
+9°
~4100
Slits
~2000
z axis
Aperture
~17
1 mm
4 mm
~1-2
Half-moon target
Tamper only side
FeMg+Tamper side
0
ZPDH Radiation
Thin CH:
T_e=167 eV,
n_e=7.1x10^{21} cm^{-3}
CH
10 μm
FeMg
Thick CH:
T_e=196 eV
n_e=3.8x10^{22} cm^{-3}
CH
68 μm
FeMg
2 μm
CH+Be:
T_e=182 eV
n_e=3.1x10^{22} cm^{-3}
Be
35 μm
CH
10 μm
FeMg

Measurements

- Te and ne of FeMg plasmas
- Source-to-sample distance
- Radiation characterization (old)
    - XRD
    - MLM

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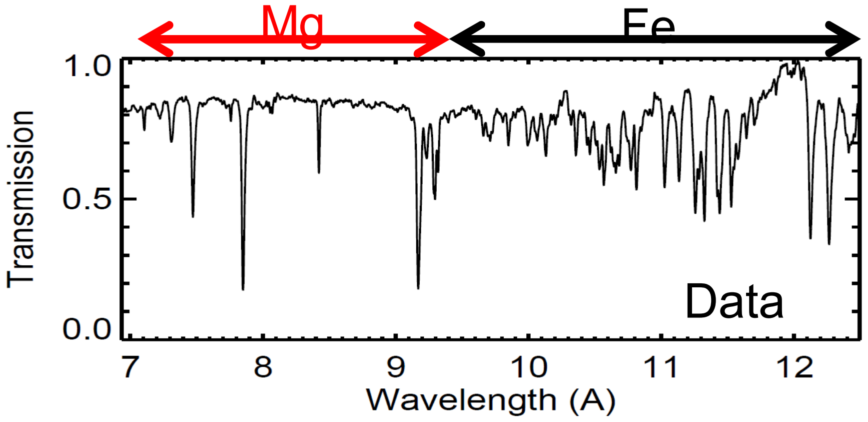
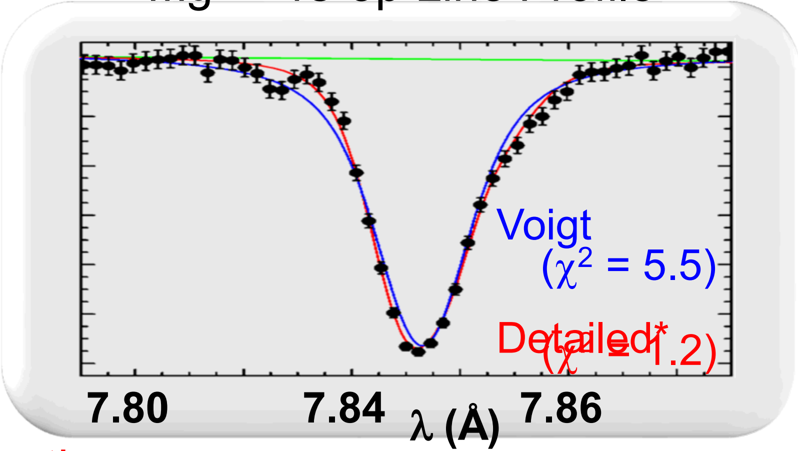
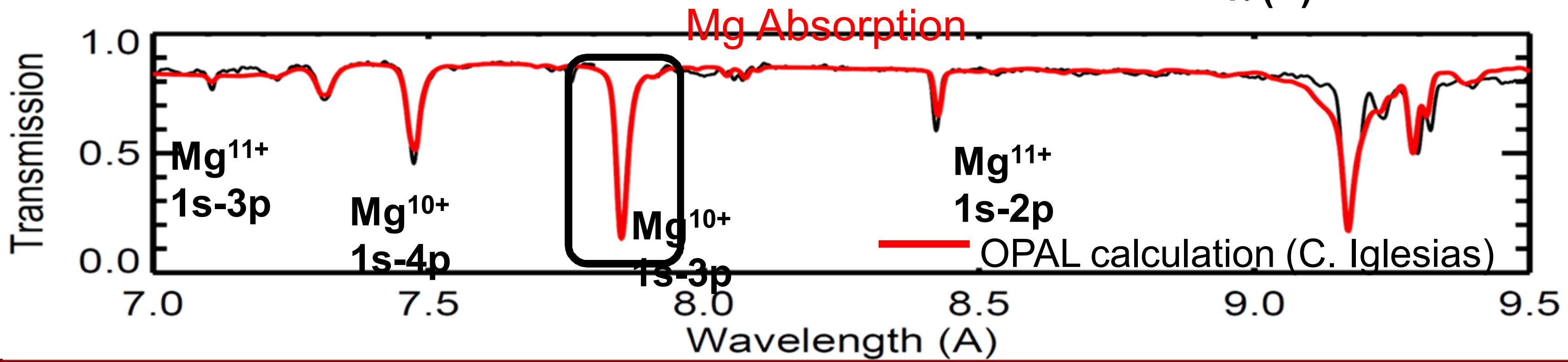
Mg K-shell spectra are mixed in with the iron to determine the plasma conditions.



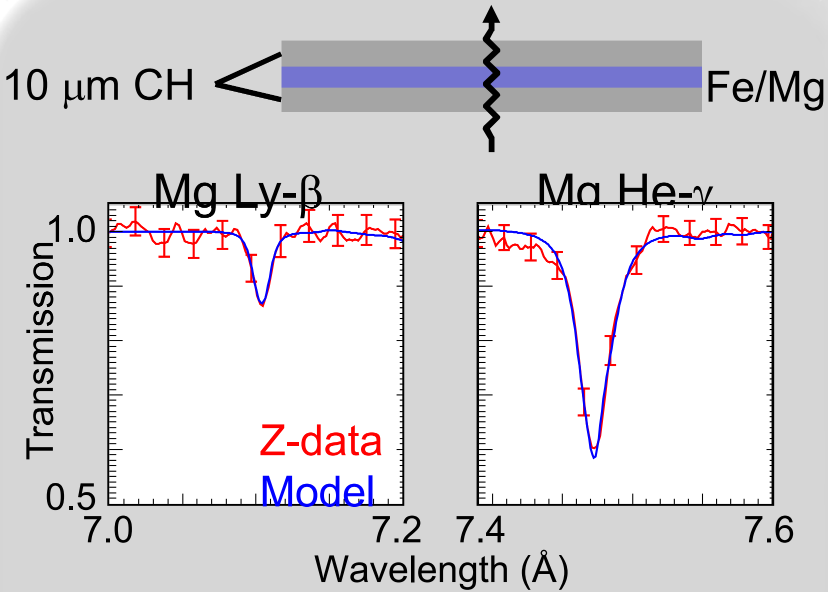




T. Nagayama et al, Phys. Plasmas **21**, 056502 (2014).

Increasing the back-side tamper mass increases the sample temperature and density

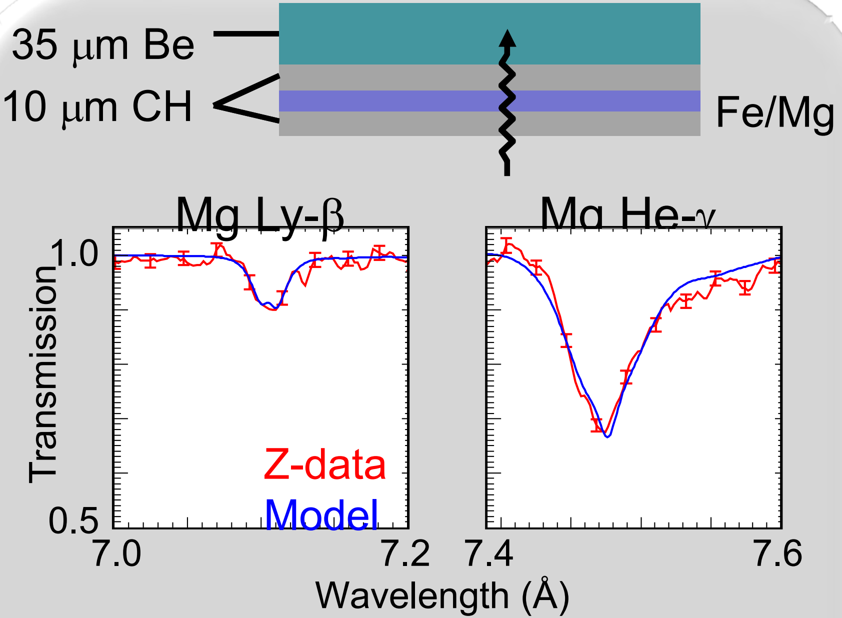
Anchor 1



$T_e = 156 \pm 6$ eV

$n_e = 6.9 \pm 1.7 \times 10^{21}$ cm^{-3}

Anchor 2



$T_e = 182 \pm 3$ eV

$n_e = 31. \pm 3. \times 10^{21}$ cm^{-3}

T. Nagayama et al, Phys. Plasmas **21**, 056502 (2014).

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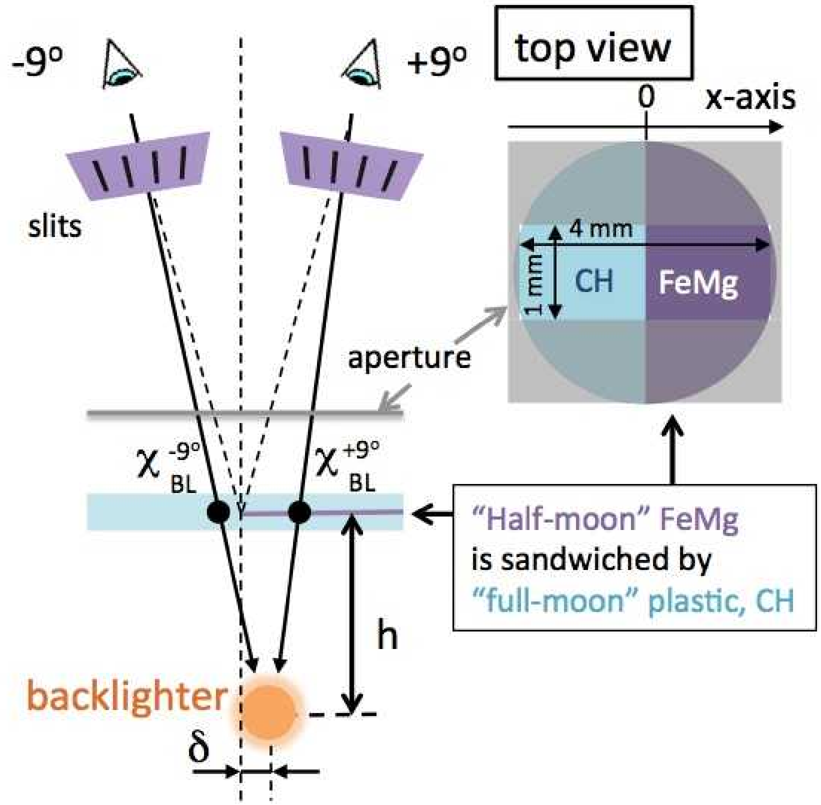
Source-to-sample distance is measured by parallax of ±9° measurements



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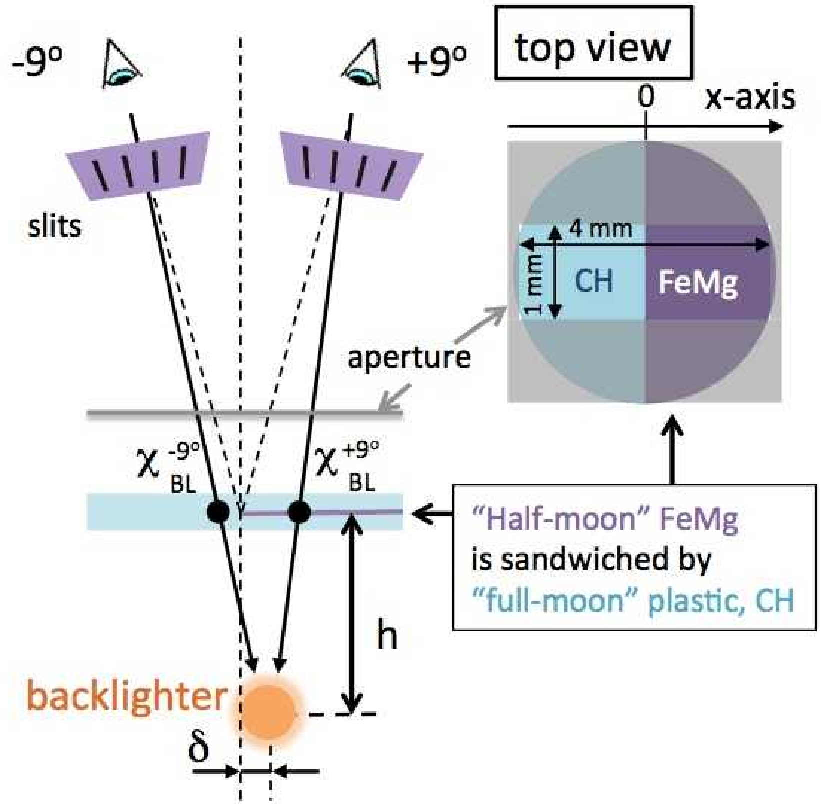

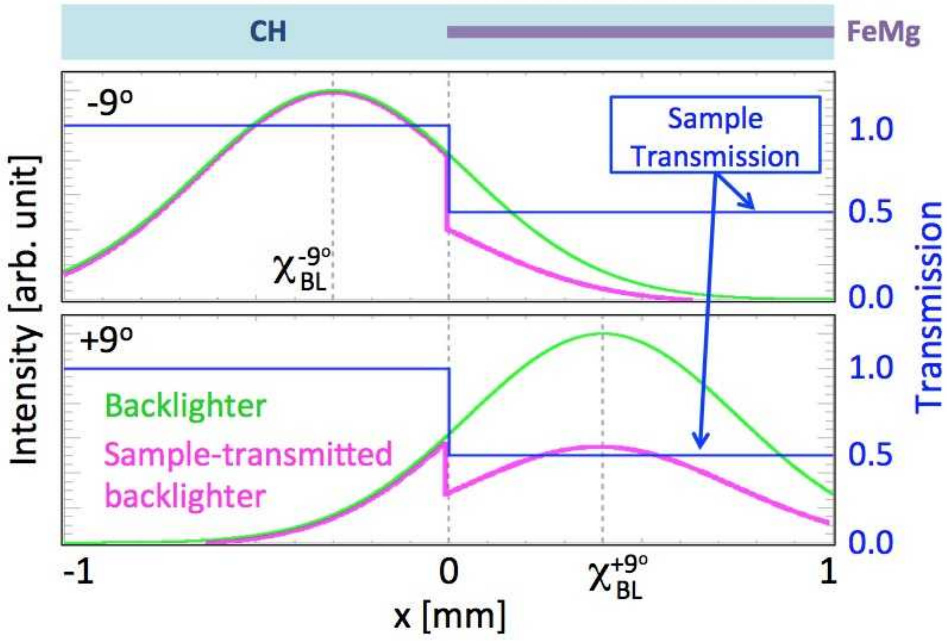

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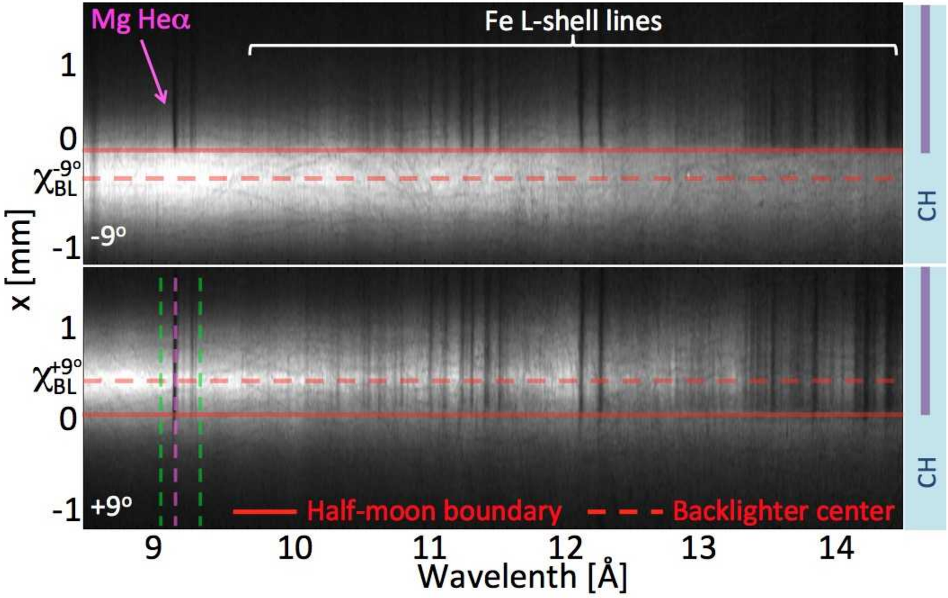

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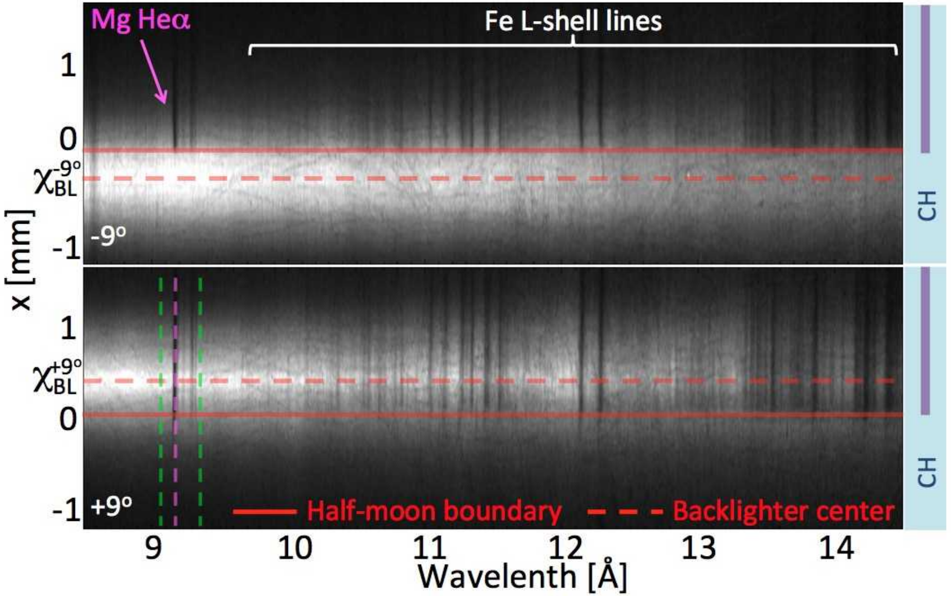

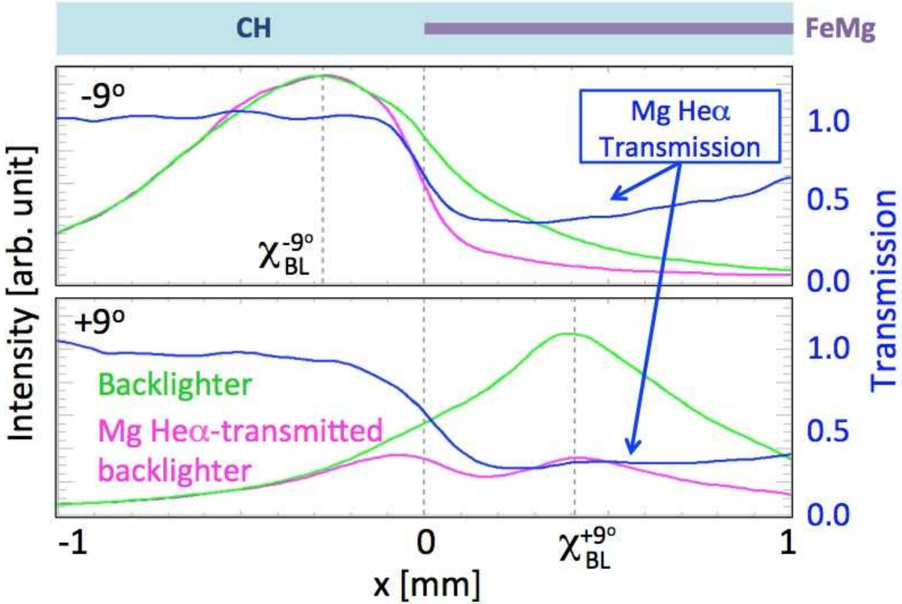

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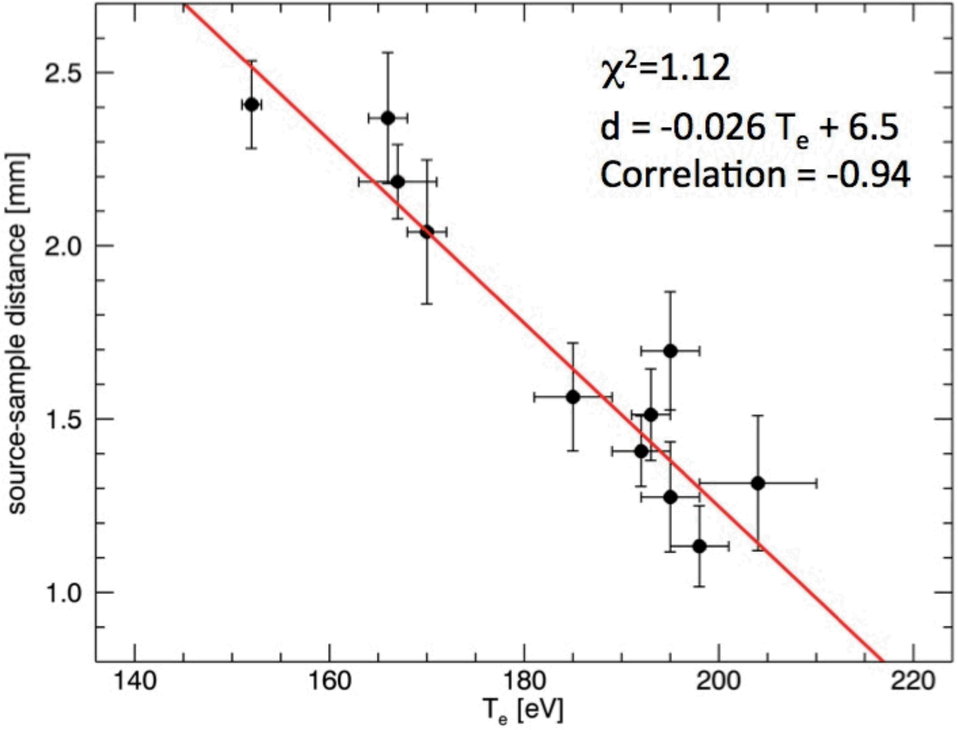
There is a strong anti-correlation between source-to-sample distance and inferred T_e



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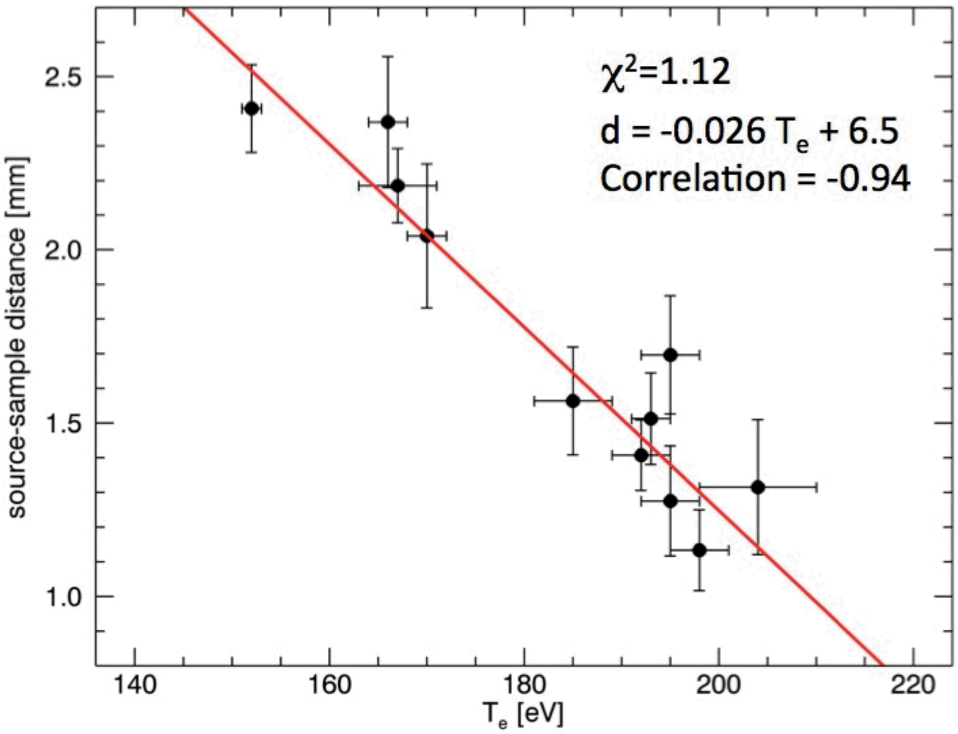

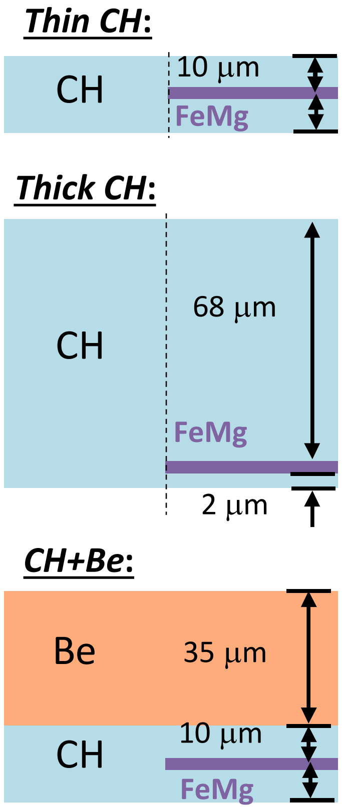

h=2.2 mm
T_e=167 eV,
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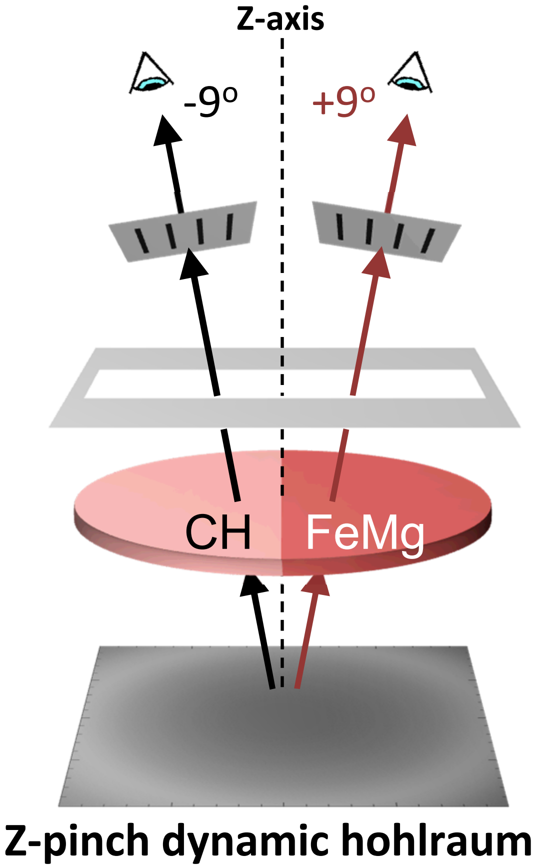
Will be discussed together with simulation

Source backlighter and sample dynamics influence the detected signals



- Heating radiation: $F_\nu(t)$
- Plasma evolution: $T_e(z, t)$, $n_e(z, t)$
- Backlighter radiation: $B_\nu(t)$
- Radiation transport

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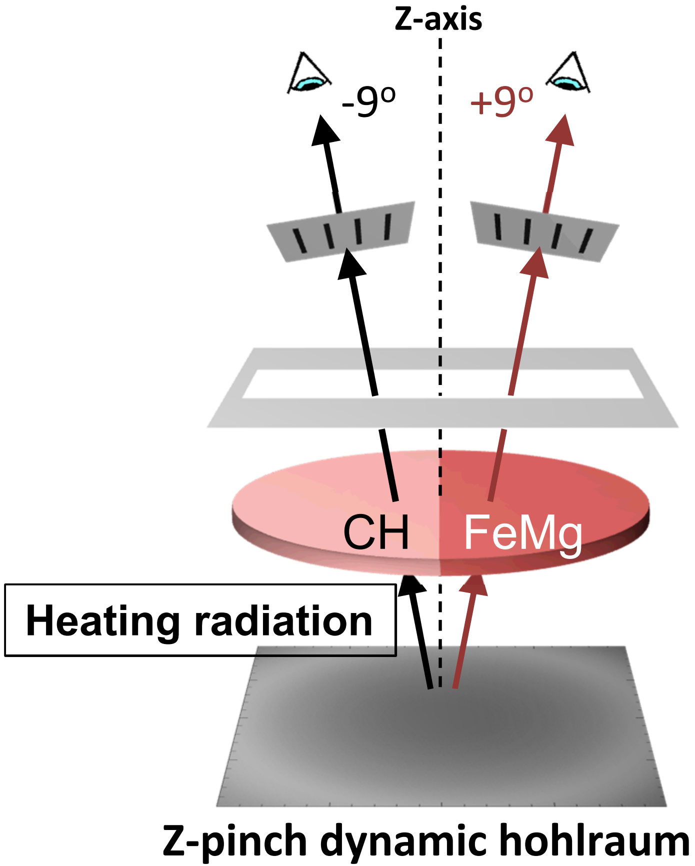

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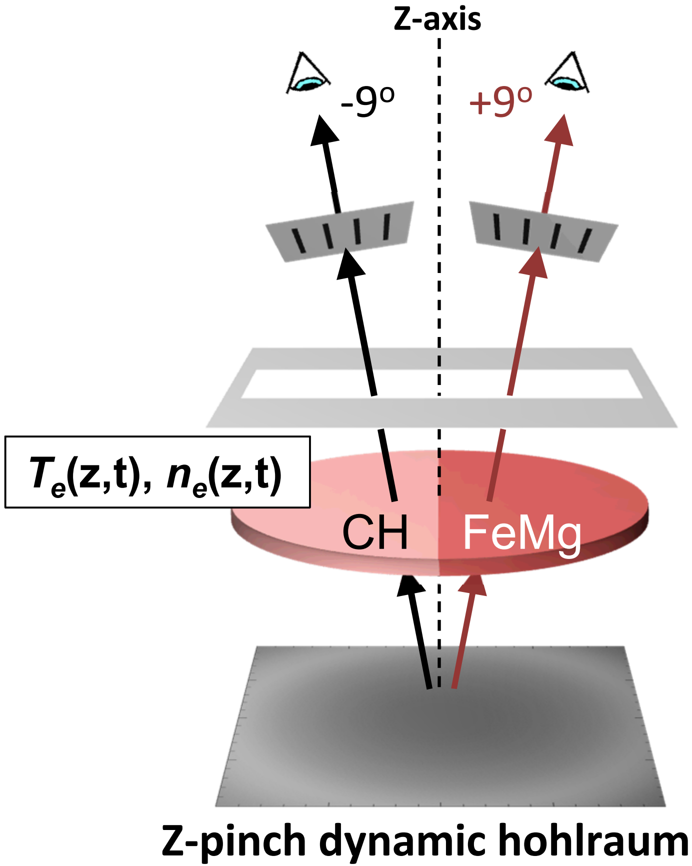

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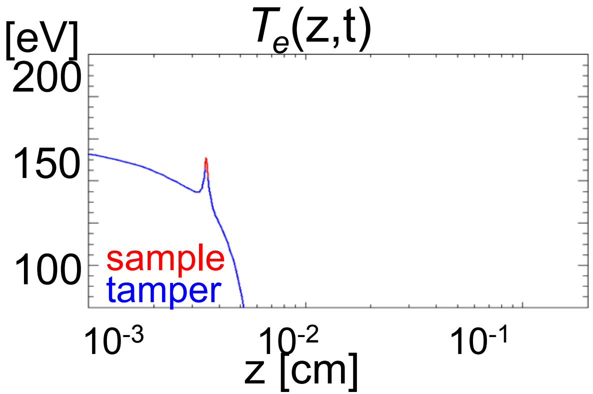

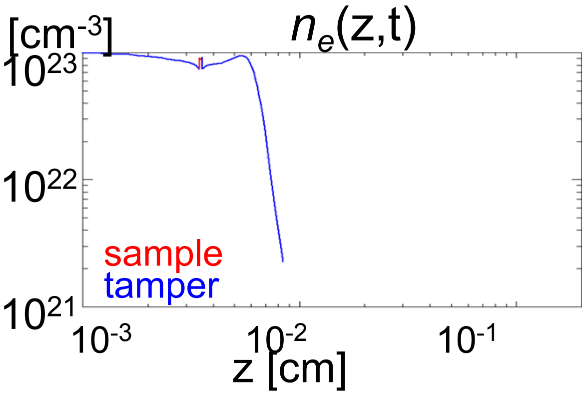

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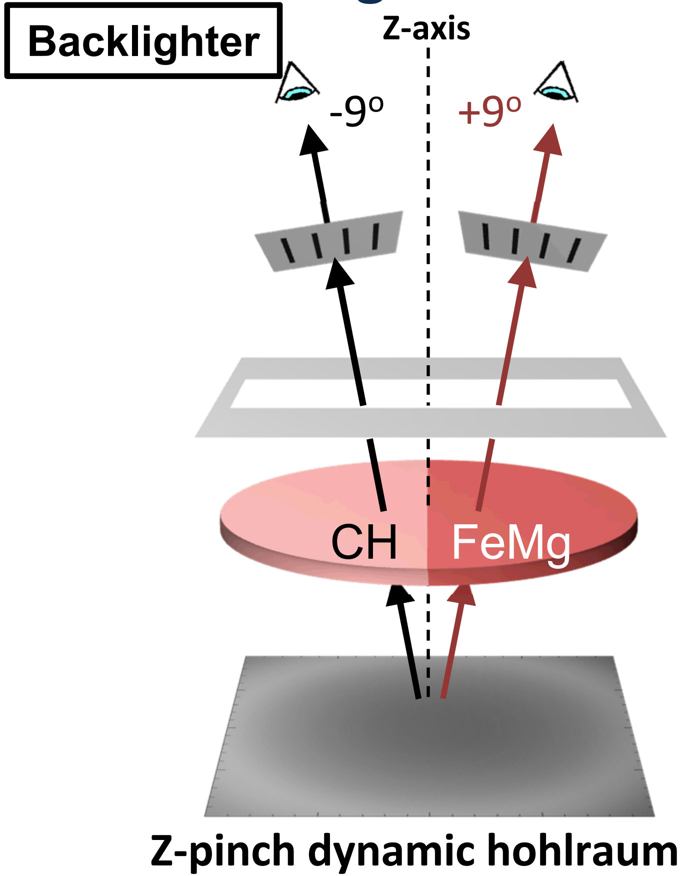

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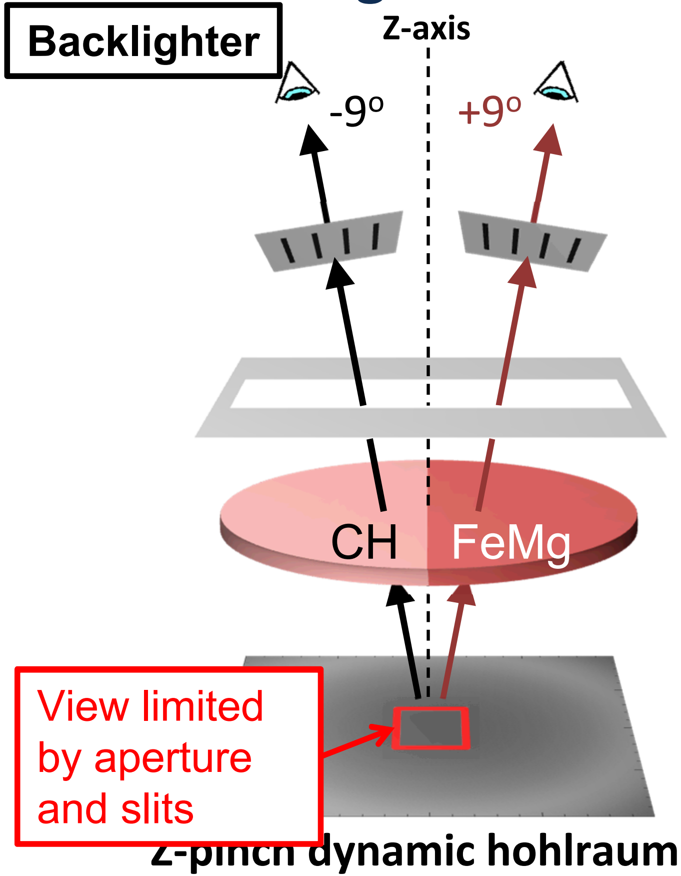
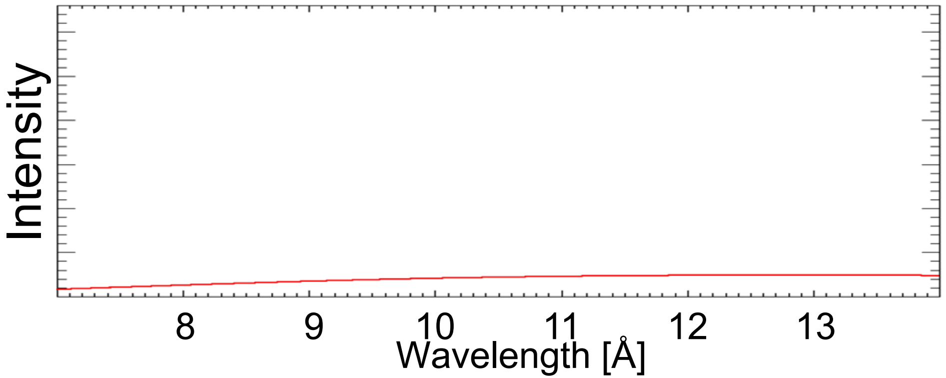
- Radiation transport

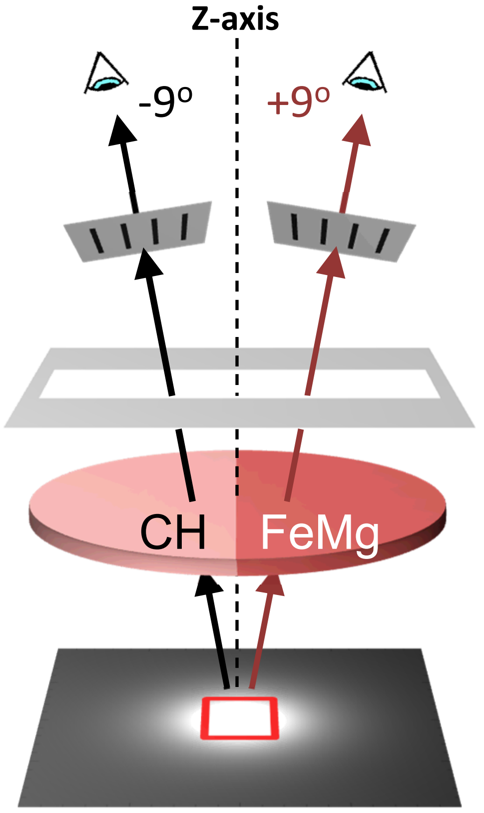
Source backlighter and sample dynamics influence the detected signals



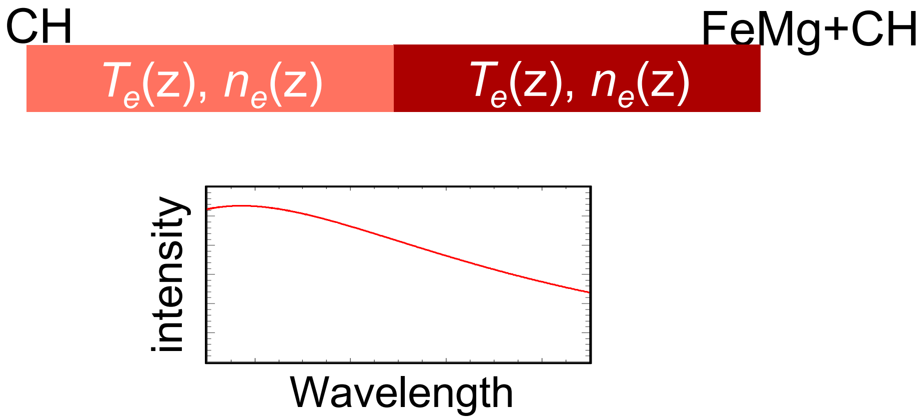
- Heating radiation: $F_{\nu}(t)$
- Plasma evolution: $T_e(z, t)$, $n_e(z, t)$
- **Backlighter radiation: $B_{\nu}(t)$**
- Radiation transport



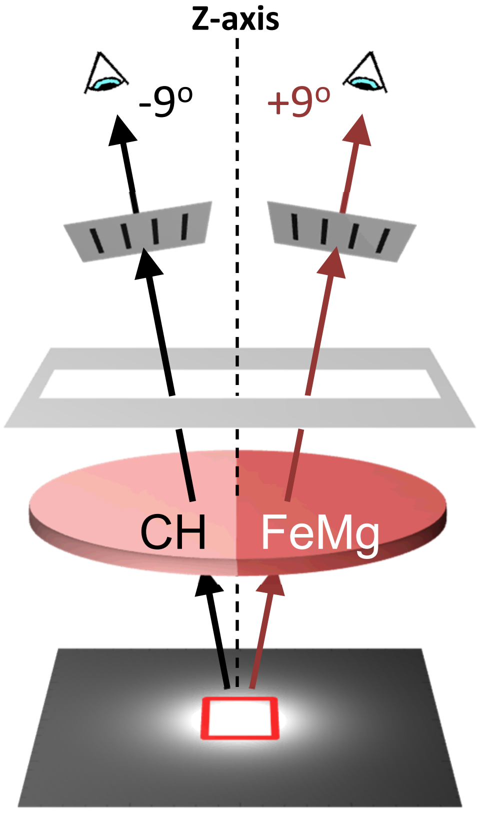
Source backlighter and sample dynamics influence the detected signals



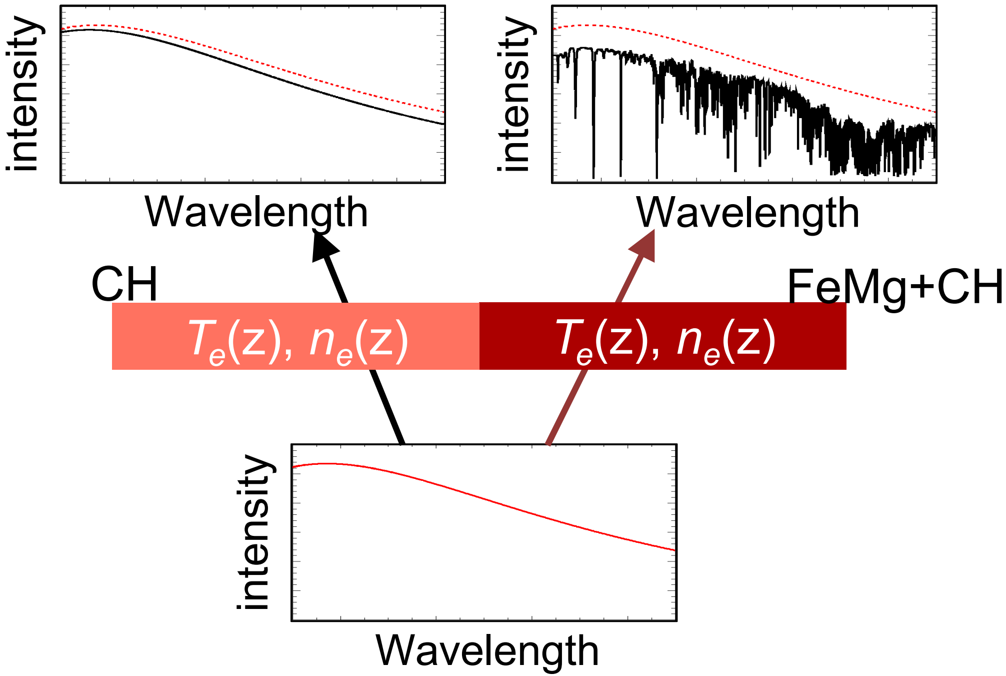
- Heating radiation: $F_\nu(t)$
- Plasma evolution: $T_e(z, t)$, $n_e(z, t)$
- Backlighter radiation: $B_\nu(t)$
- **Radiation transport**



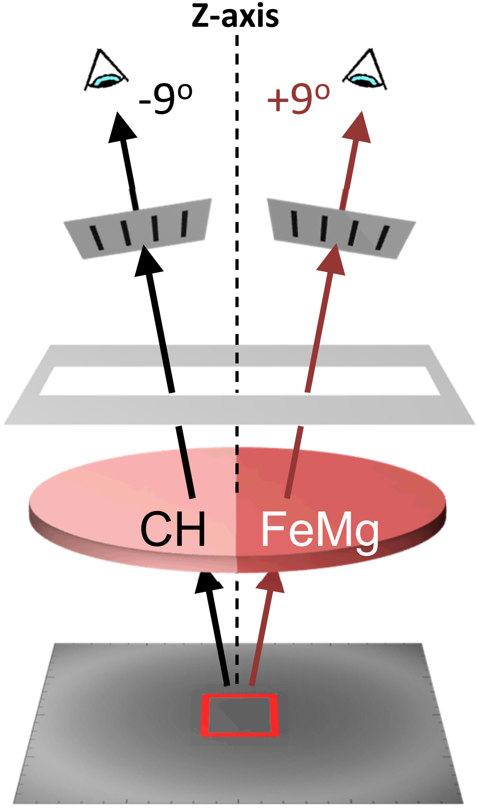
Source backlighter and sample dynamics influence the detected signals



- Heating radiation: $F_\nu(t)$
- Plasma evolution: $T_e(z, t)$, $n_e(z, t)$
- Backlighter radiation: $B_\nu(t)$
- **Radiation transport**

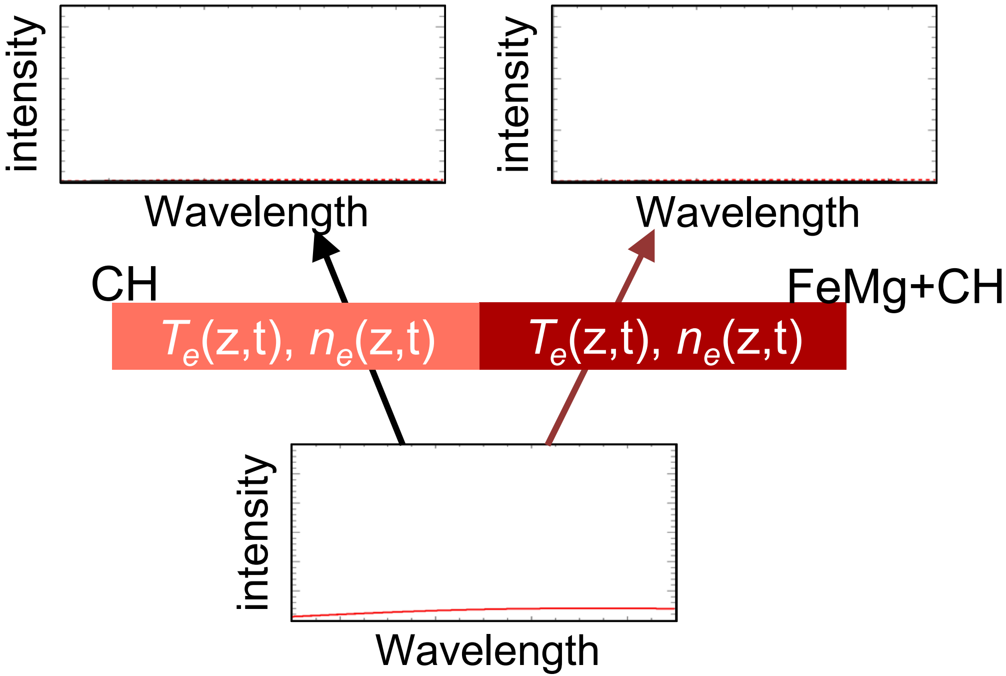


Source backlighter and sample dynamics influence the detected signals

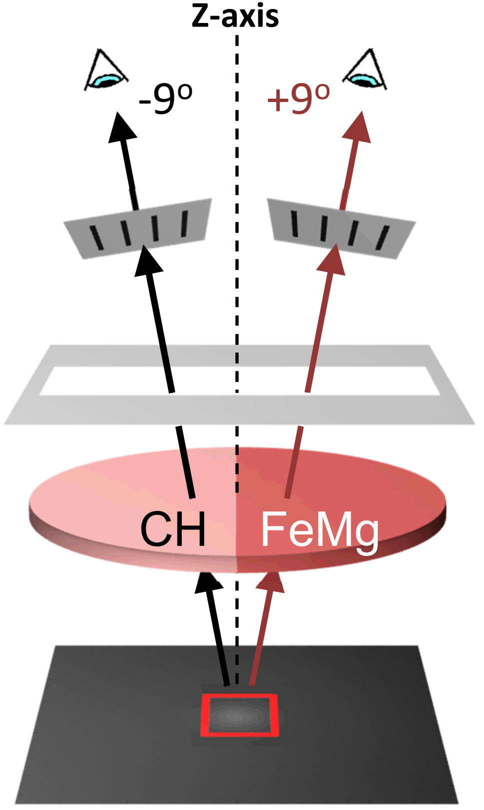


Z-pinch dynamic hohlraum

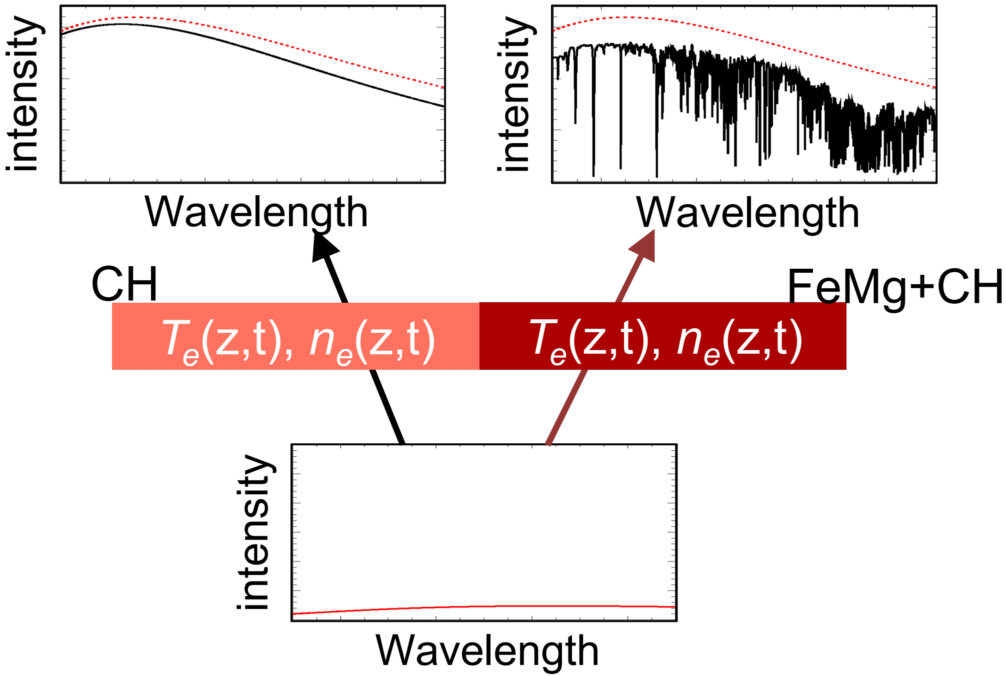
- Heating radiation: $F_\nu(t)$
- Plasma evolution: $T_e(z, t)$, $n_e(z, t)$
- Backlighter radiation: $B_\nu(t)$
- **Radiation transport**



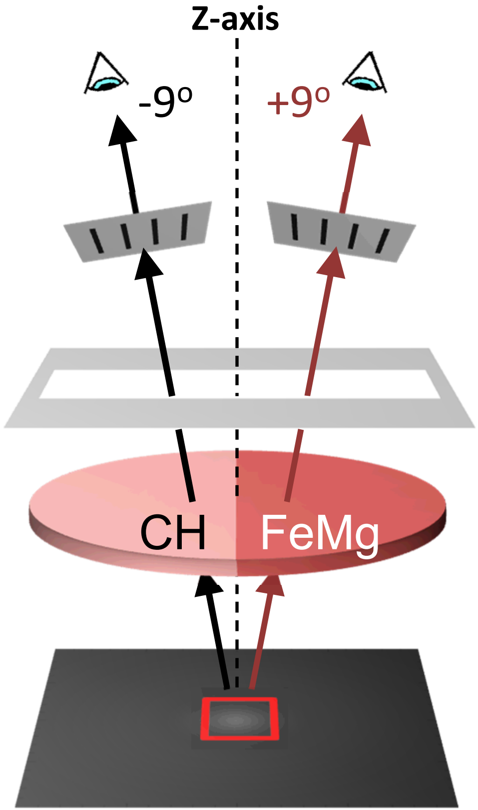
Source backlighter and sample dynamics influence the detected signals



- Heating radiation: $F_\nu(t)$
- Plasma evolution: $T_e(z, t)$, $n_e(z, t)$
- Backlighter radiation: $B_\nu(t)$
- **Radiation transport**



Simulation bridges static-uniform picture of data and dynamic-gradient picture of reality



Z-pinch dynamic hohlraum

Simulating our measurements

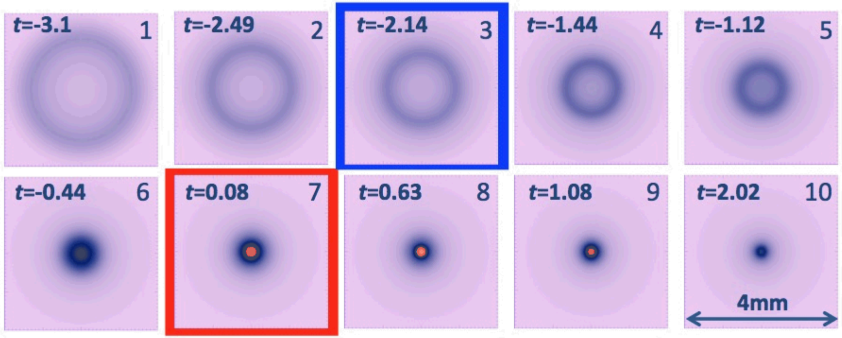
Heating radiation
- Gated ZPDH pinhole images
- 3D view factor code (VISRAD)

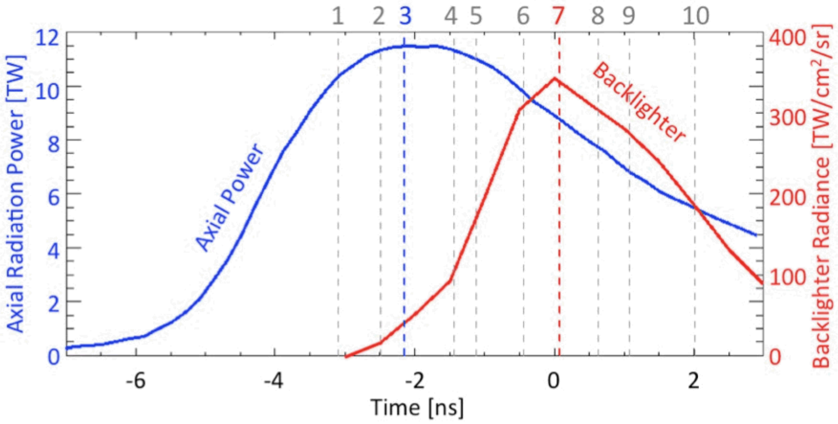
Sample/tamper hydrodynamics
- 1D Lagrangian hydrodynamics code (HELIOS)

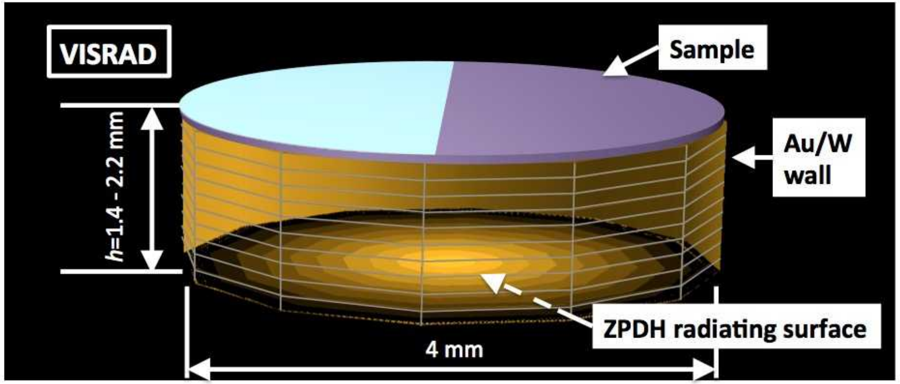
Backlighter radiation
- Gated ZPDH pinhole images
- Integrate over detector-observable area

Radiation transport
- PrismSPECT LTE emissivity and opacity database
- Numerically integrate radiation transport equation

Drive radiation is modeled with VISRAD using pinhole images calibrated with XRD power measurements

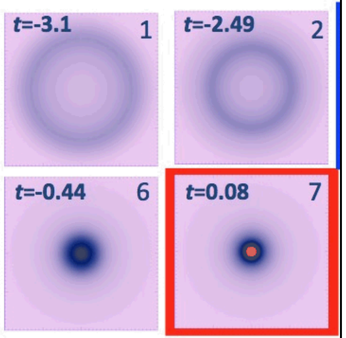


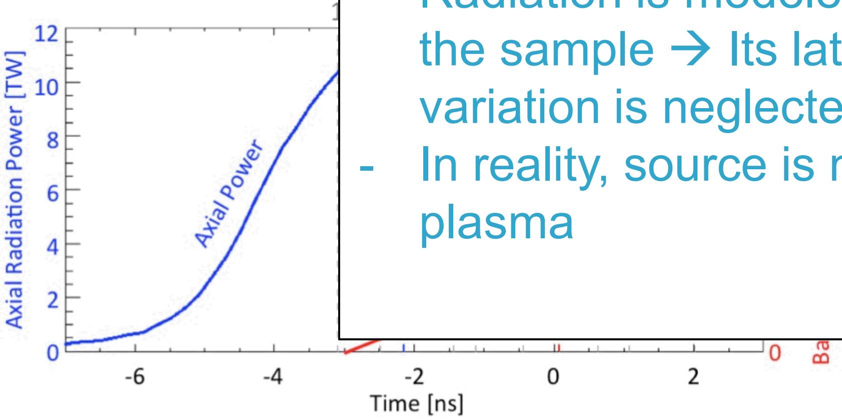


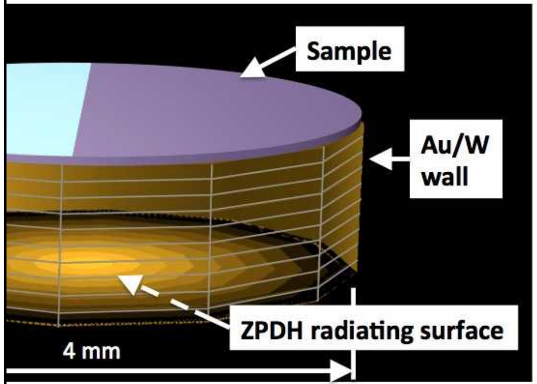


1. Calibrate pinhole images with XRD
2. Design concentric ZPDH source, sample, and surrounding gold components
3. VISRAD simulate radiation time history on sample

Drive radiation is modeled with VISRAD using pinhole images calibrated with XRD power measurements







Limitations:

- Radiation of ZR is assumed to be a simple scale on the calibrated pinhole images
- Radiation is modeled at the center of the sample → Its lateral and axial variation is neglected.
- In reality, source is not a disk but a 3D plasma

hole images with XRD
ntric ZPDH source,
surrounding gold

ate radiation time
history on sample

T. Nagayama et al, Phys. Rev. E **93**, 023202 (2016).

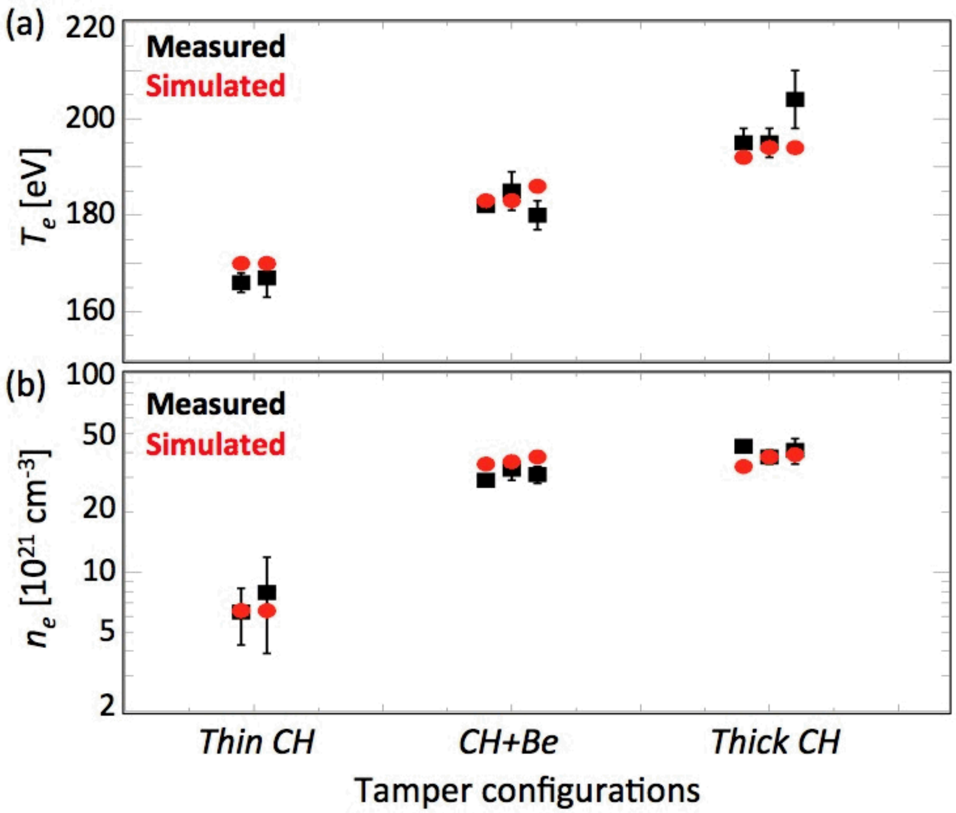
Hydro-simulation Details:

- Free parameters:
  - Scale factor to match the measured sample temperature (C=x2.6)
  - Drive onset to match the measured sample density (t_0=-1.0ns)
- Fix the lower boundary of the sample

- Helios - 1D Lagrangian code
- PROPACEOS for EOS and Opacity
- No inline geometrical dilution
- Disk for radiation source geometry

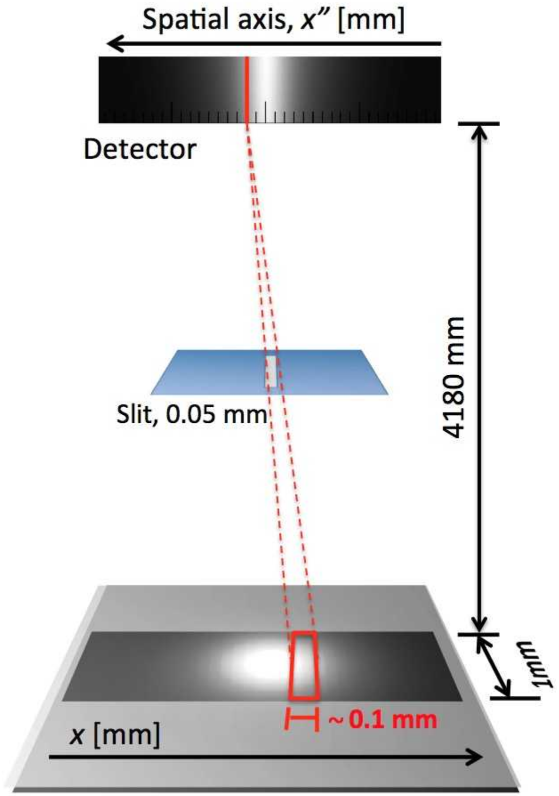
Same source and backlighter worked to simulate all experiments

T_e and n_e inferred from simulation agree with measured ones



T. Nagayama et al, Phys. Rev. E **93**, 023202 (2016).

Spectral images are simulated by taking into account instrumental geometry



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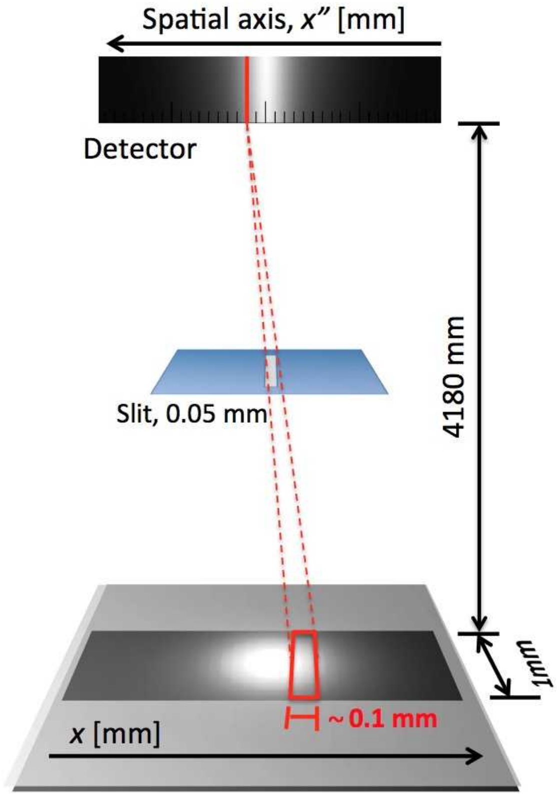

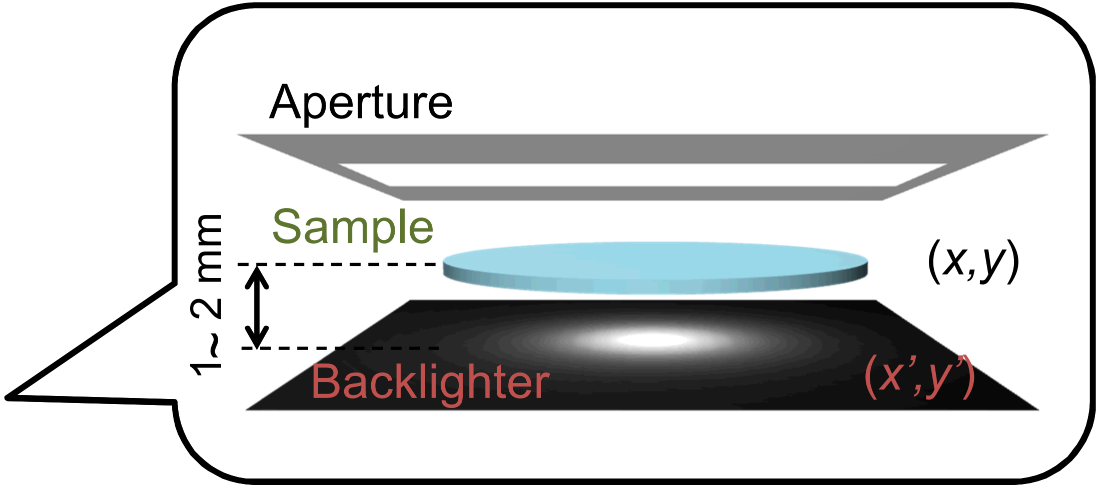

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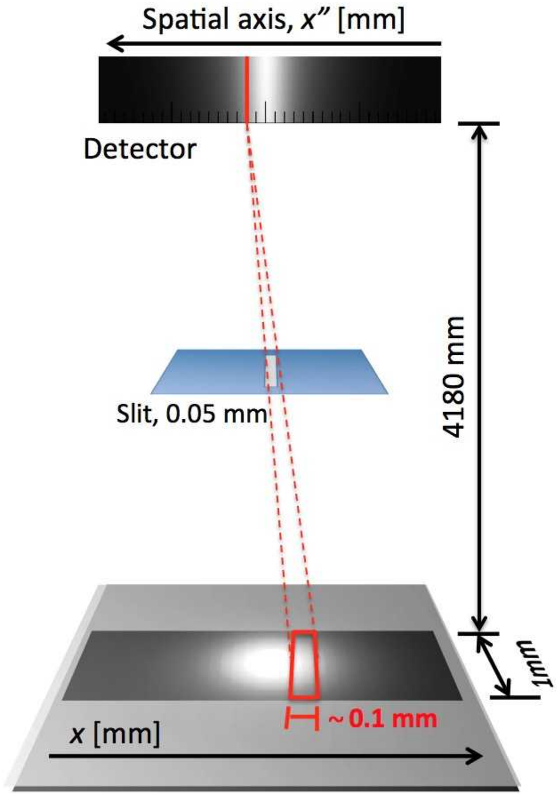

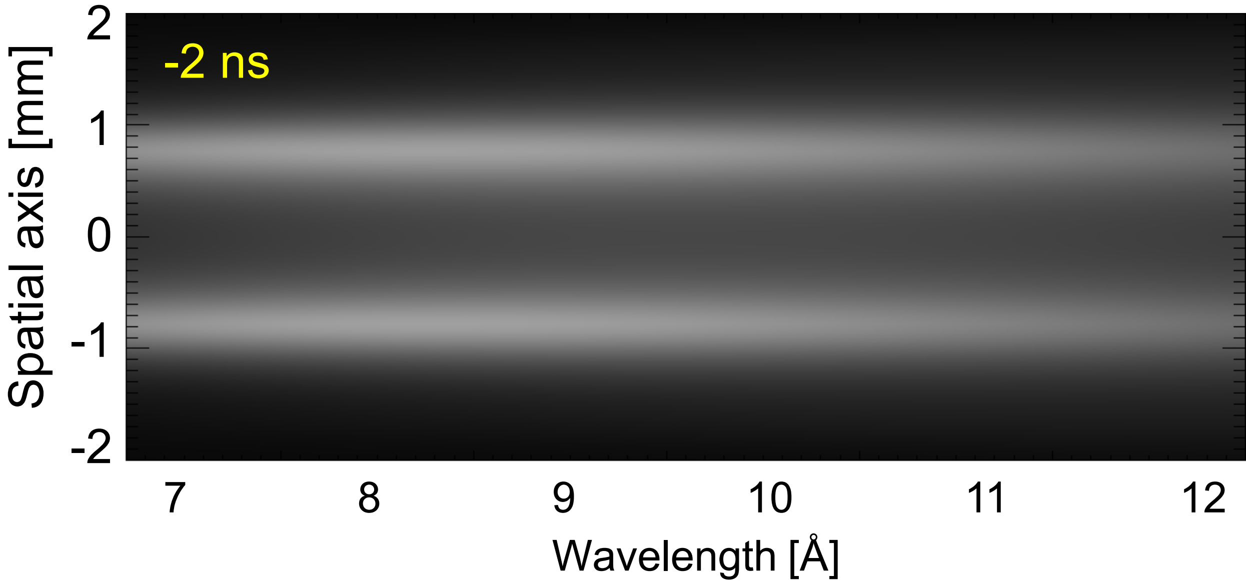

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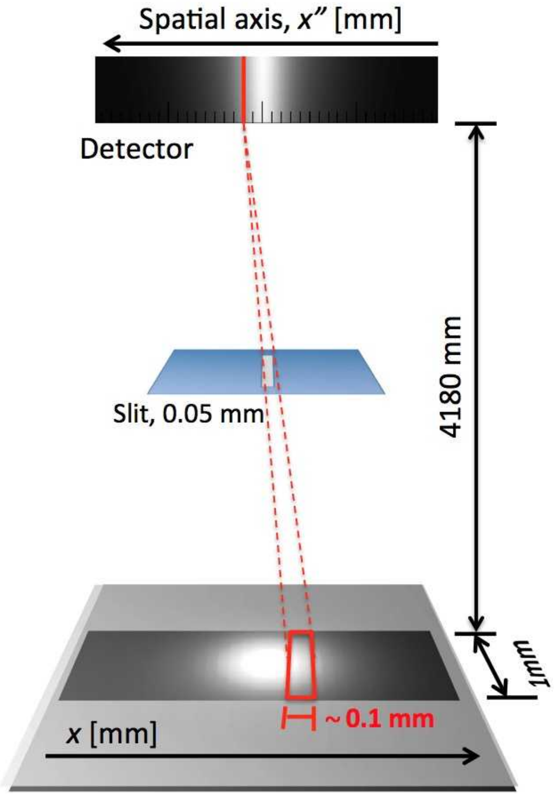

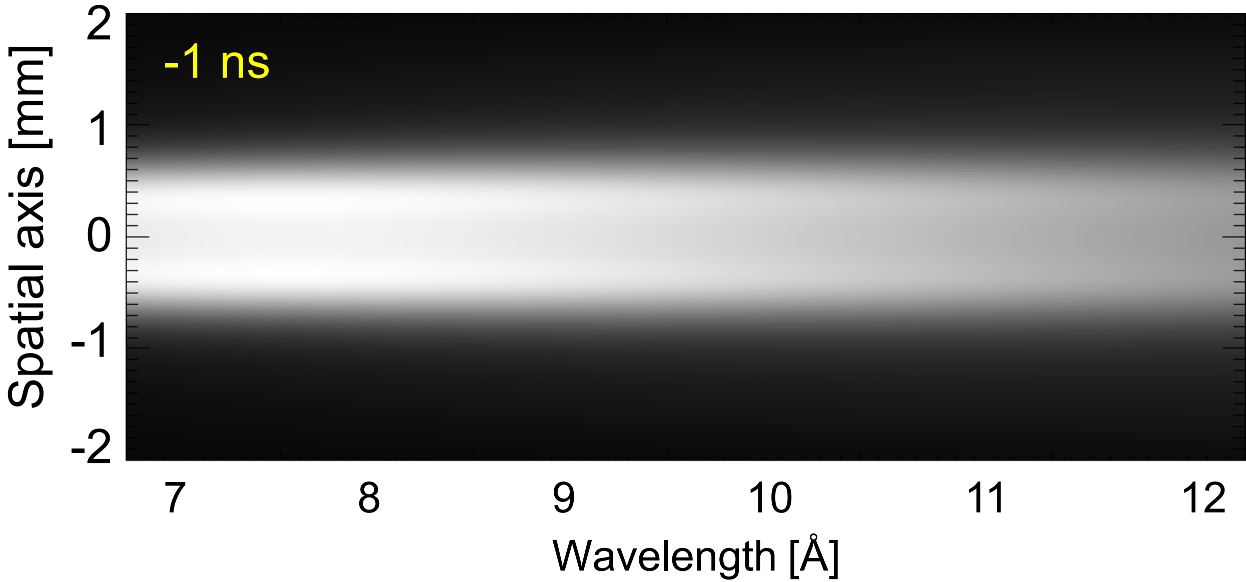

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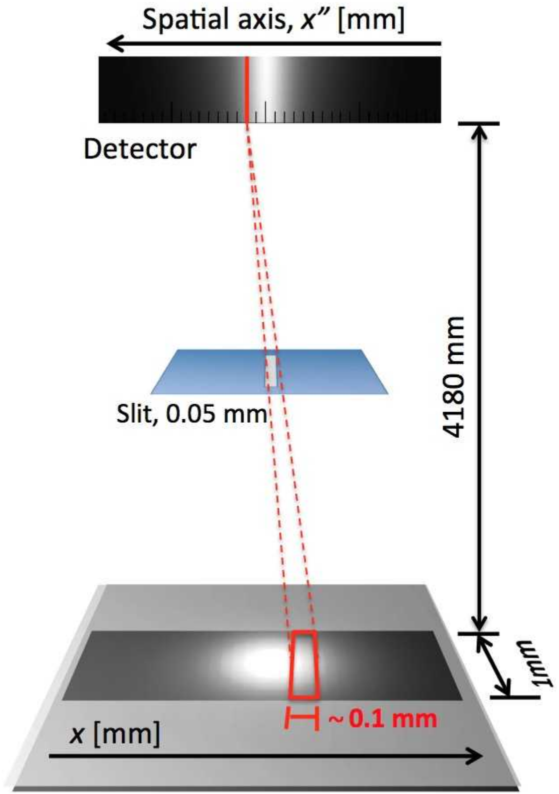

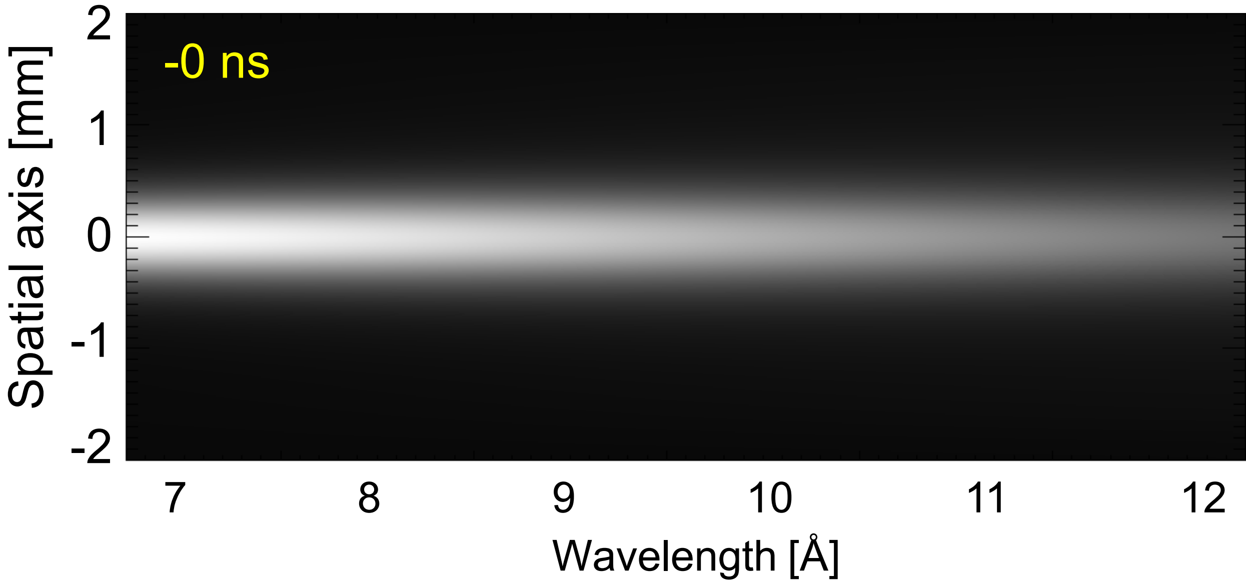

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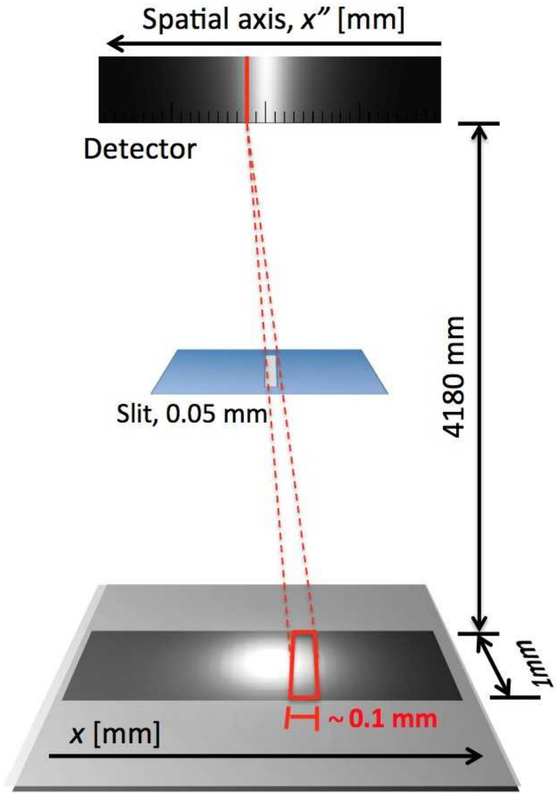

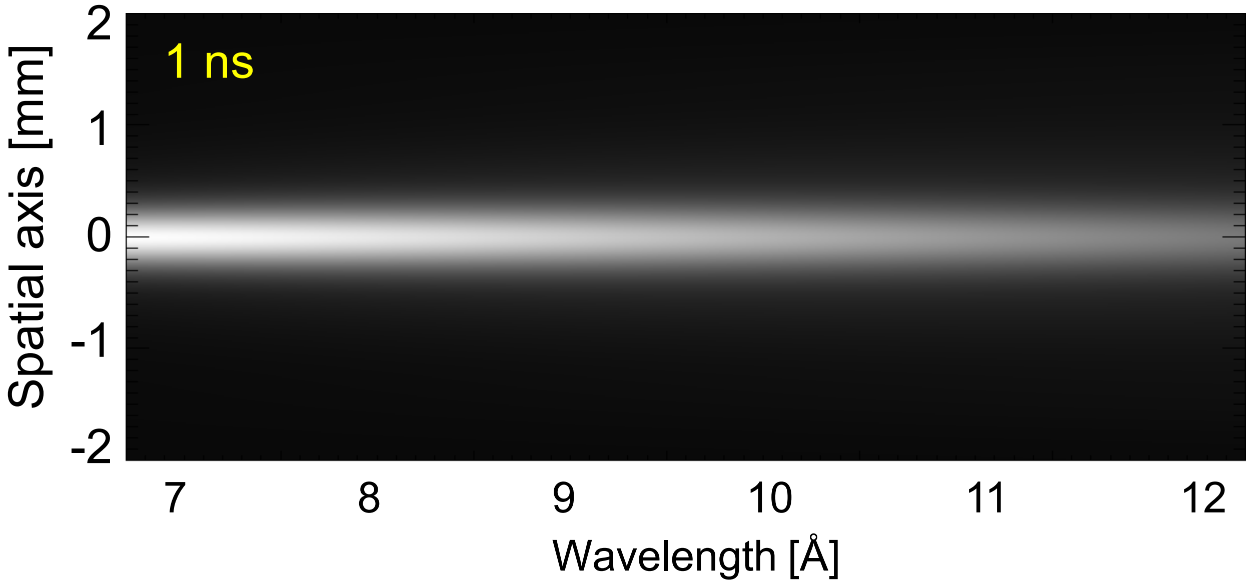

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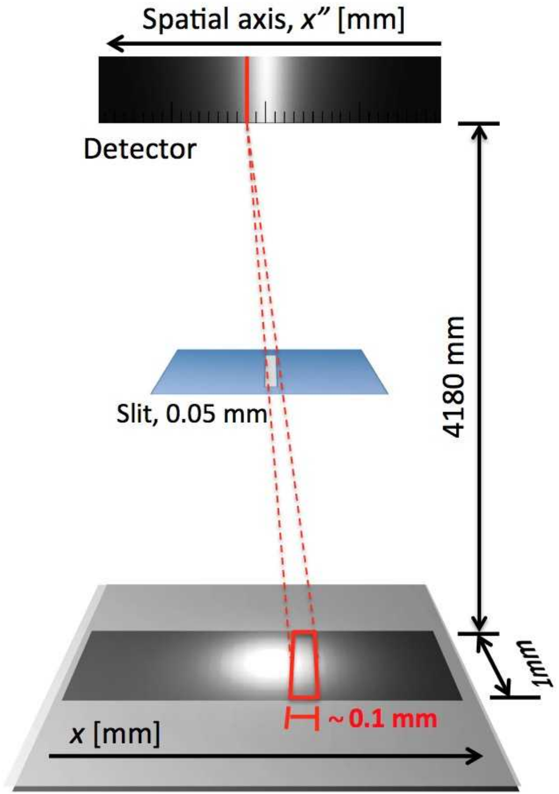
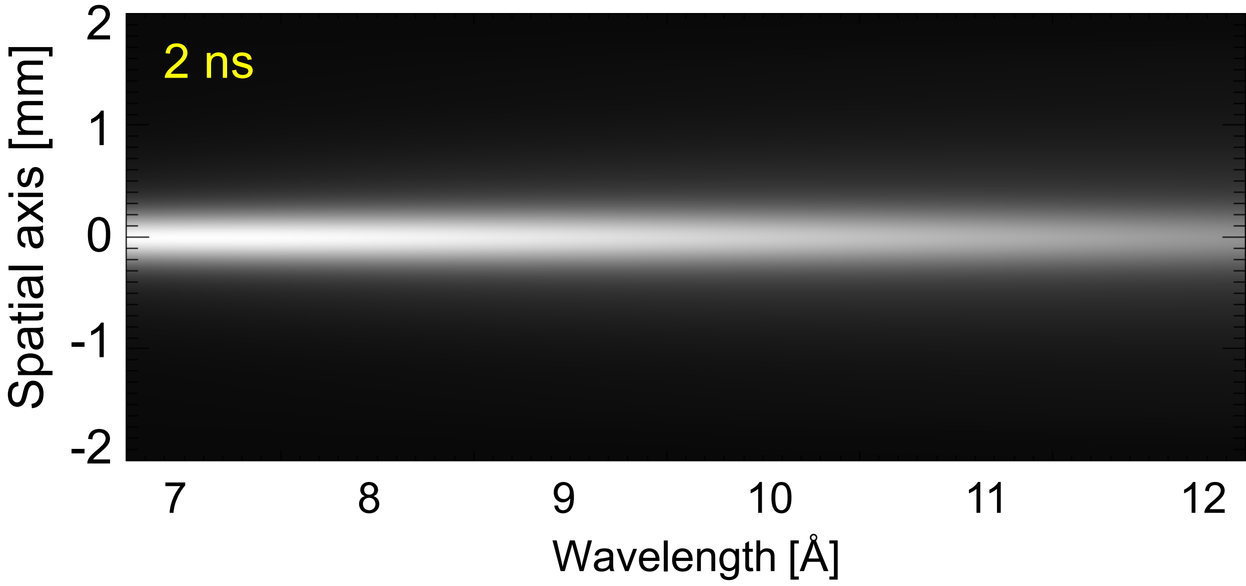
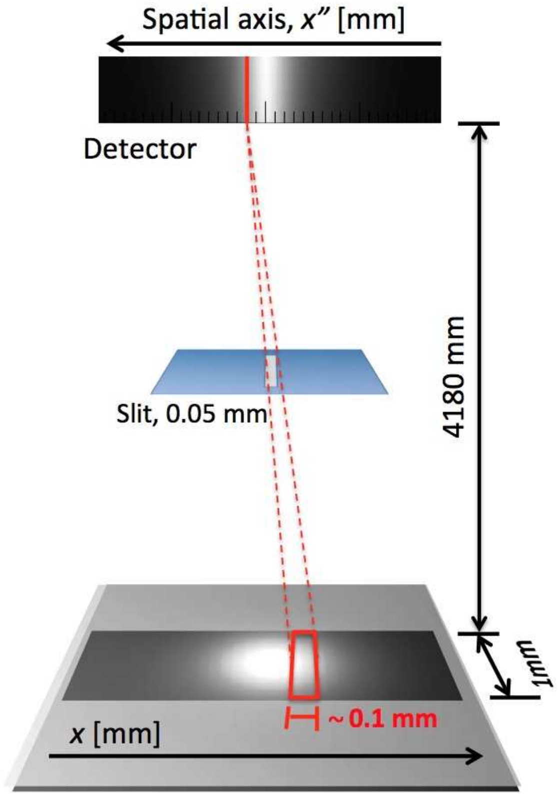
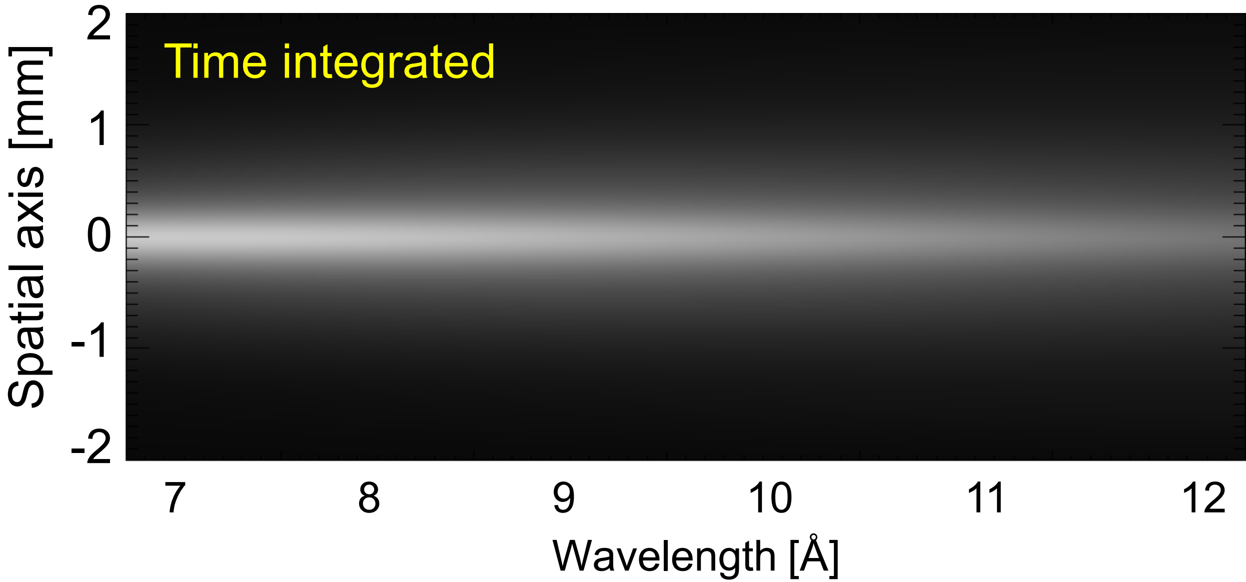




T. Nagayama et al, Phys. Rev. E **93**, 023202 (2016).

Spectral images are simulated by taking into account instrumental geometry





T. Nagayama et al, Phys. Rev. E **93**, 023202 (2016).

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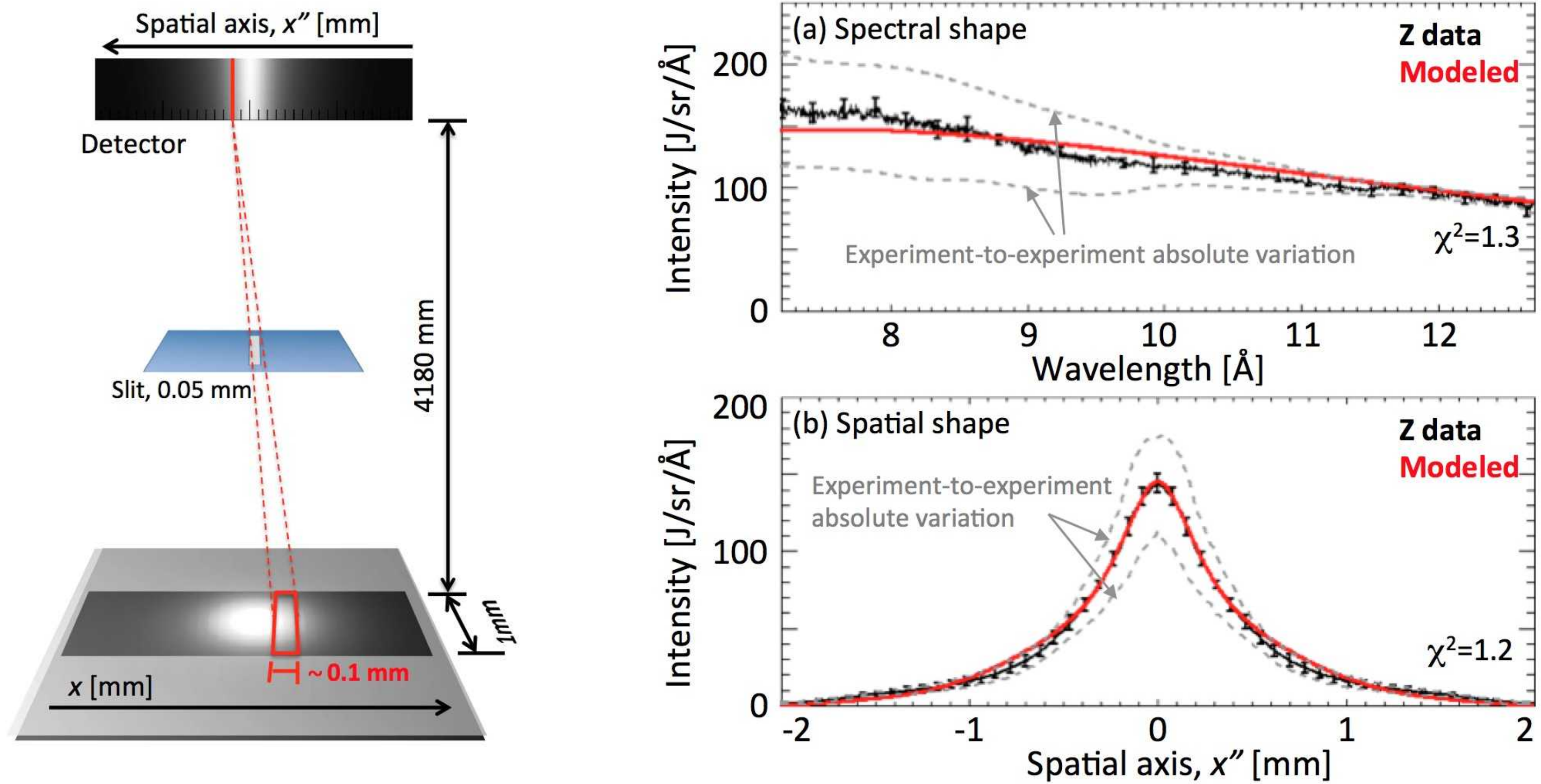
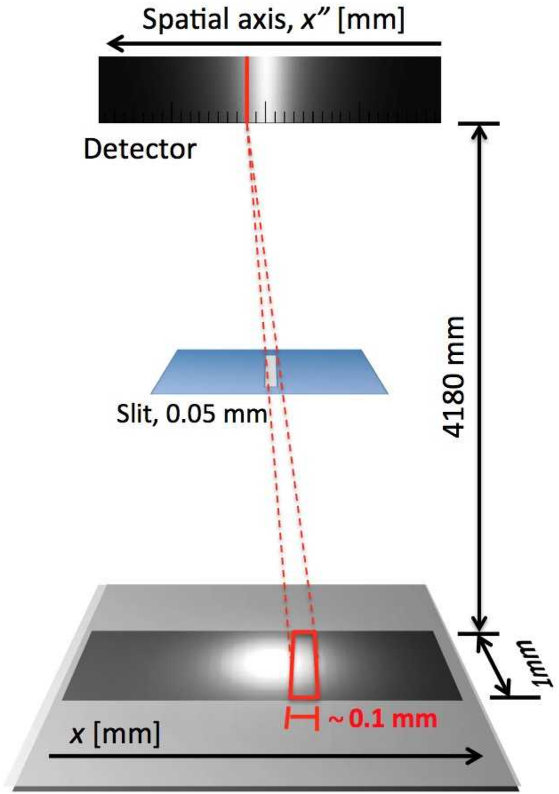
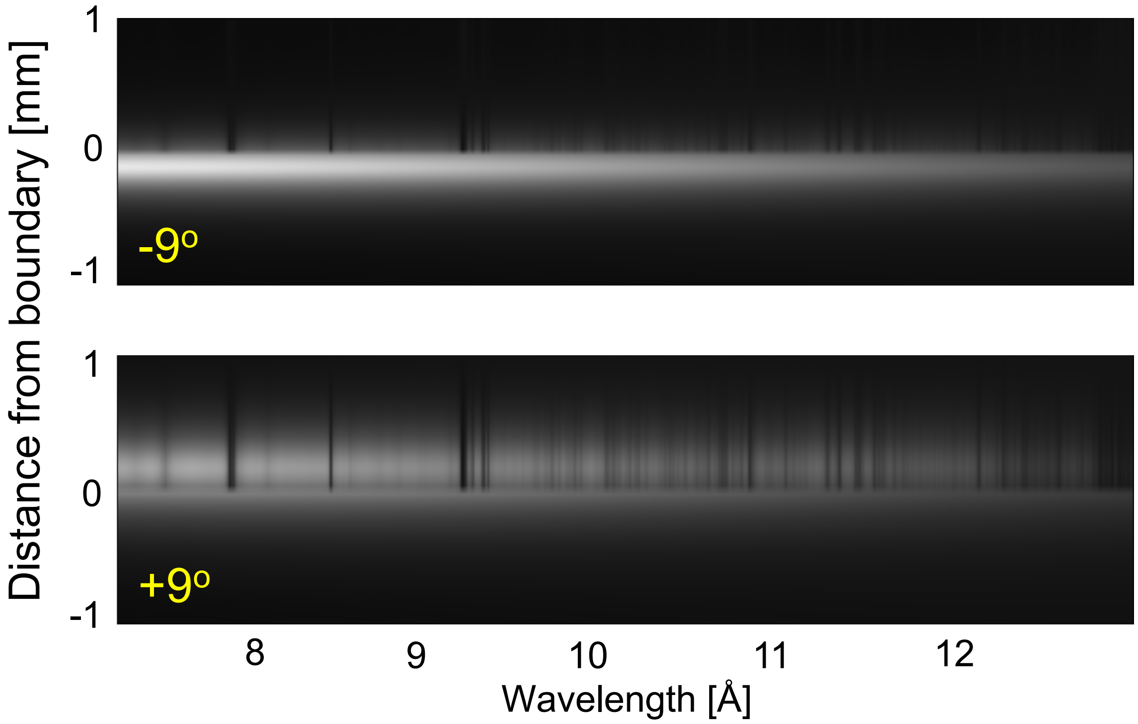


T. Nagayama et al, Phys. Rev. E **93**, 023202 (2016).

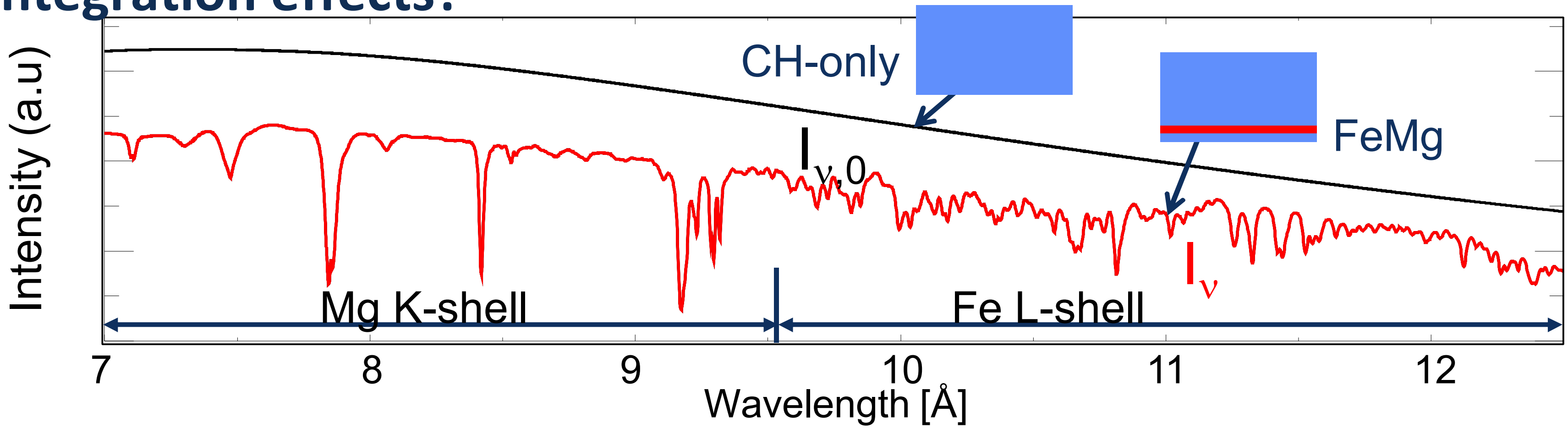
Half-moon images are simulated by solving detailed radiation transport through the target gradient





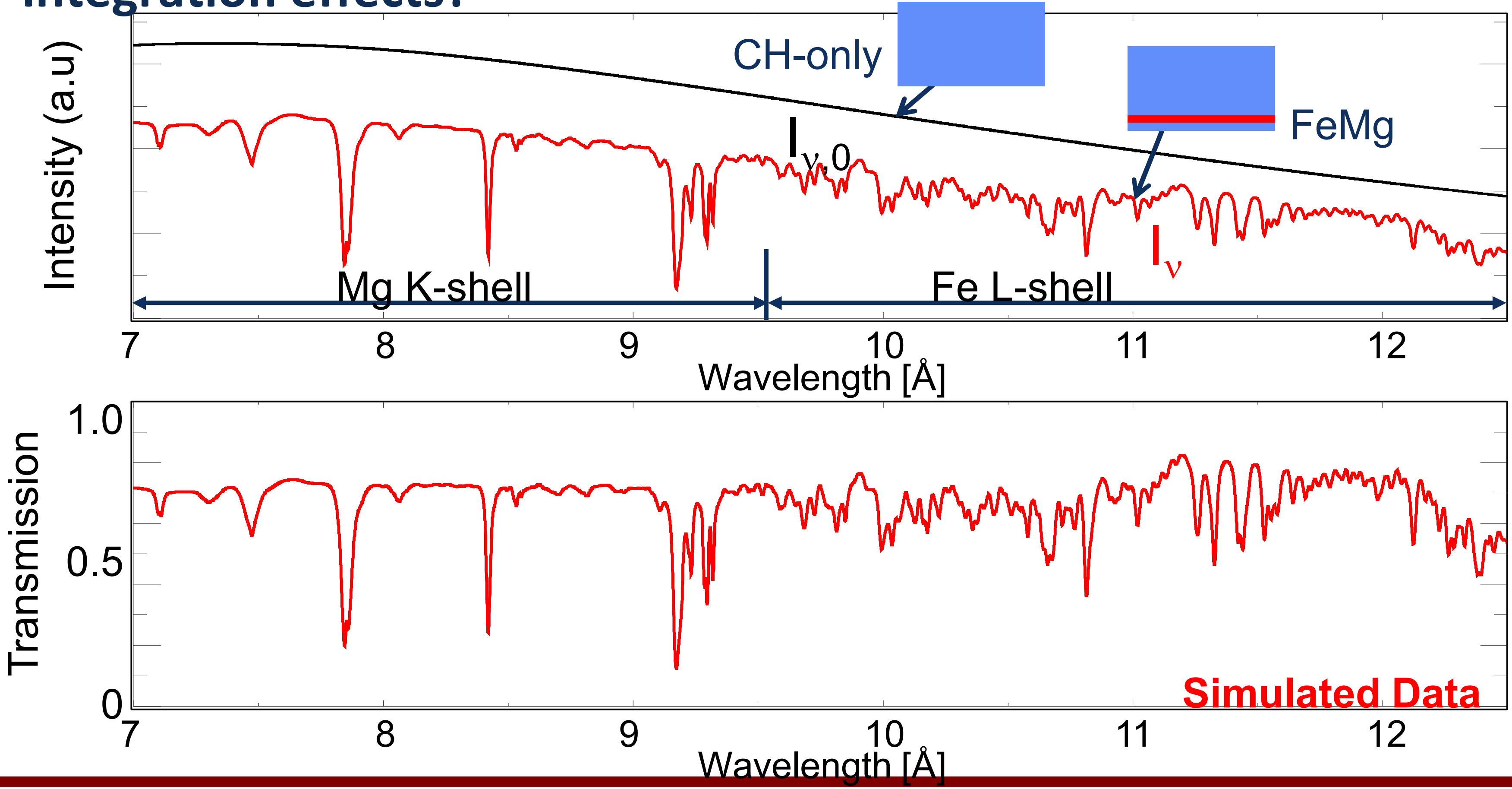
T. Nagayama et al, Phys. Rev. E **93**, 023202 (2016).

Are the discrepancies caused by the time- and space-integration effects?



1. Simulate our $I_{\nu,0}$ and I_ν
   - FeMg and CH emission/attenuation
   - $T_e(z,t)$, $n_e(z,t)$
   - Backlighter time history, $B_\nu(t)$
2. Analyze $I_{\nu,0}$ and I_ν in the same way as the data

Are the discrepancies caused by the time- and space-integration effects?



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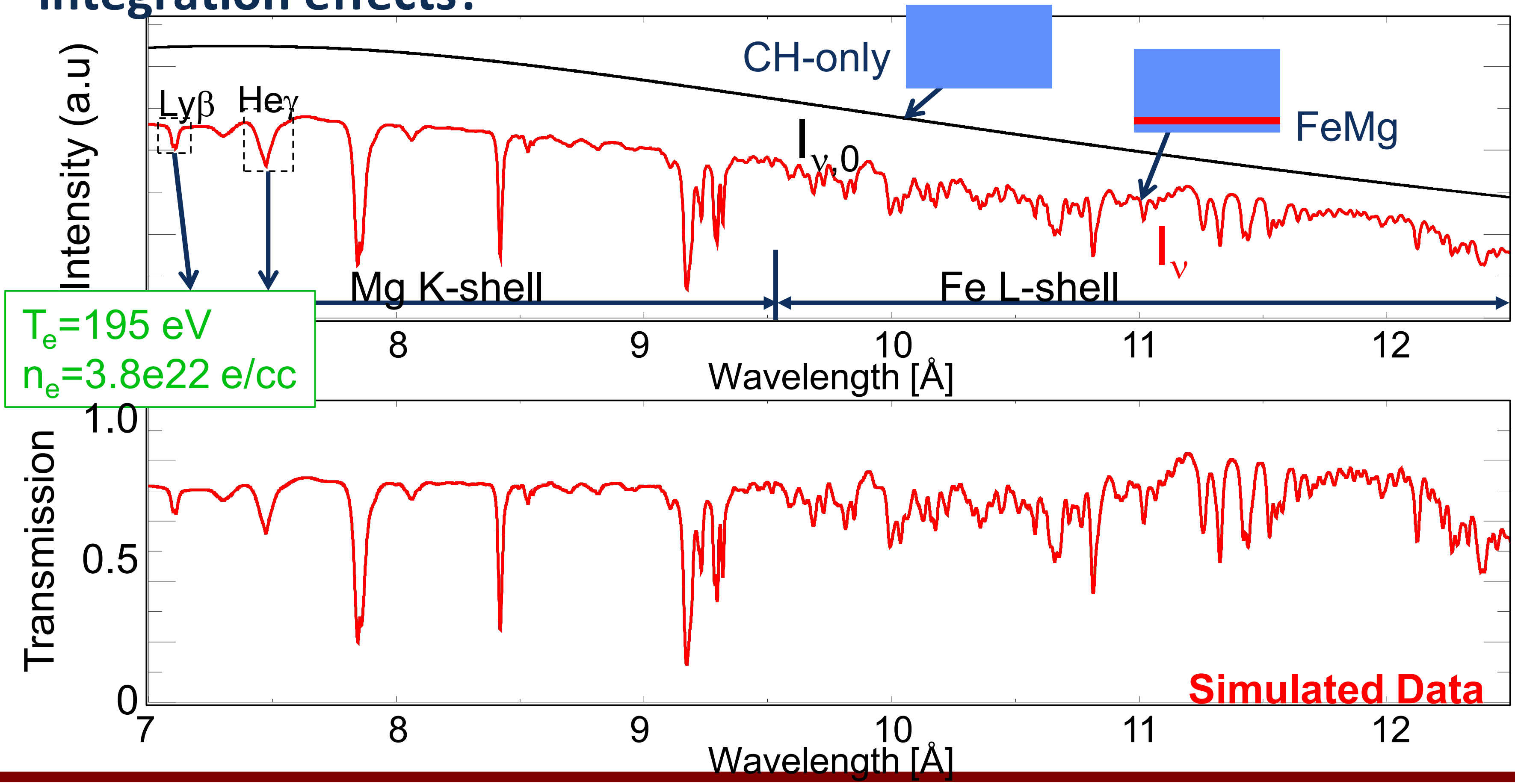

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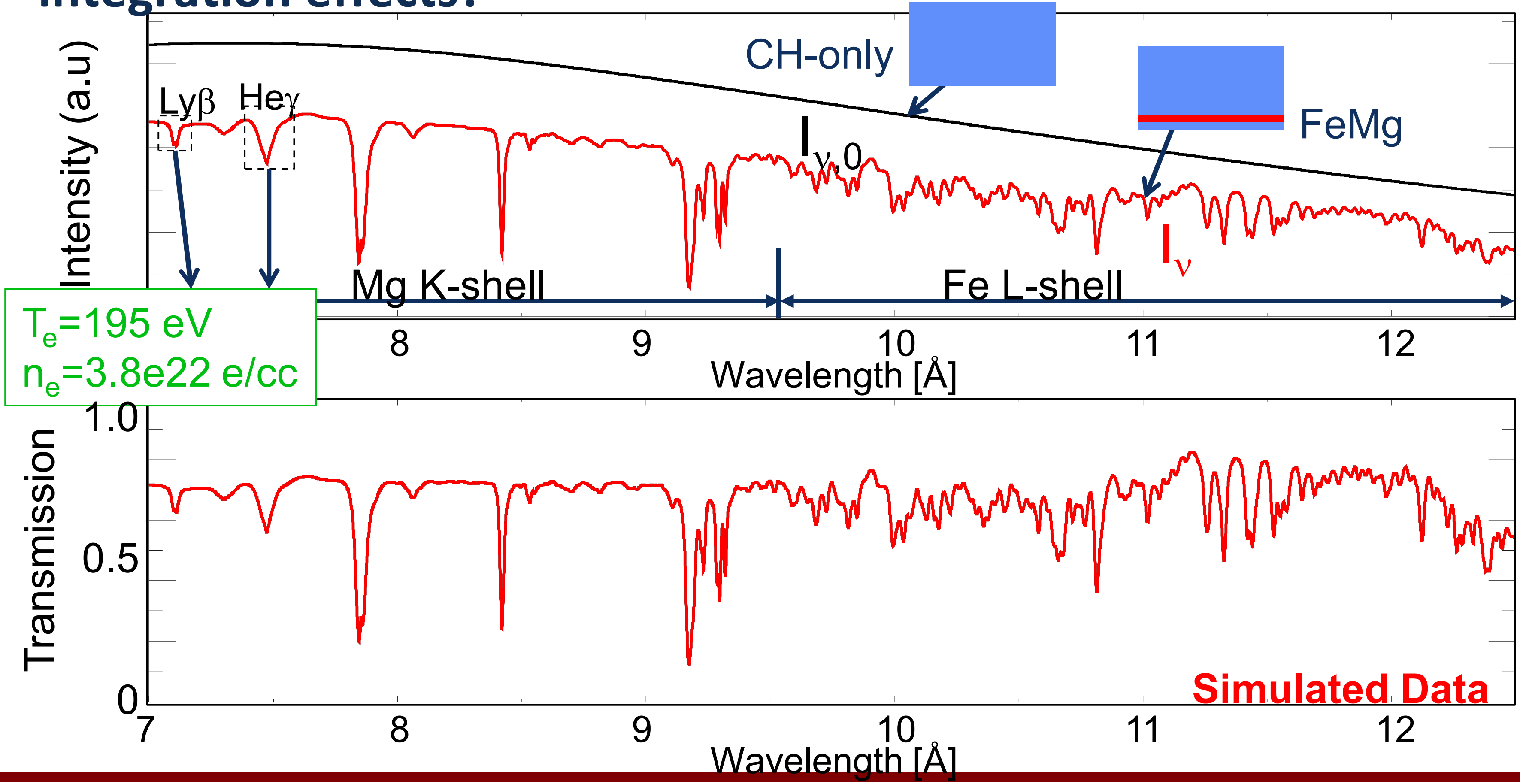

Are the discrepancies caused by the time- and space-integration effects?

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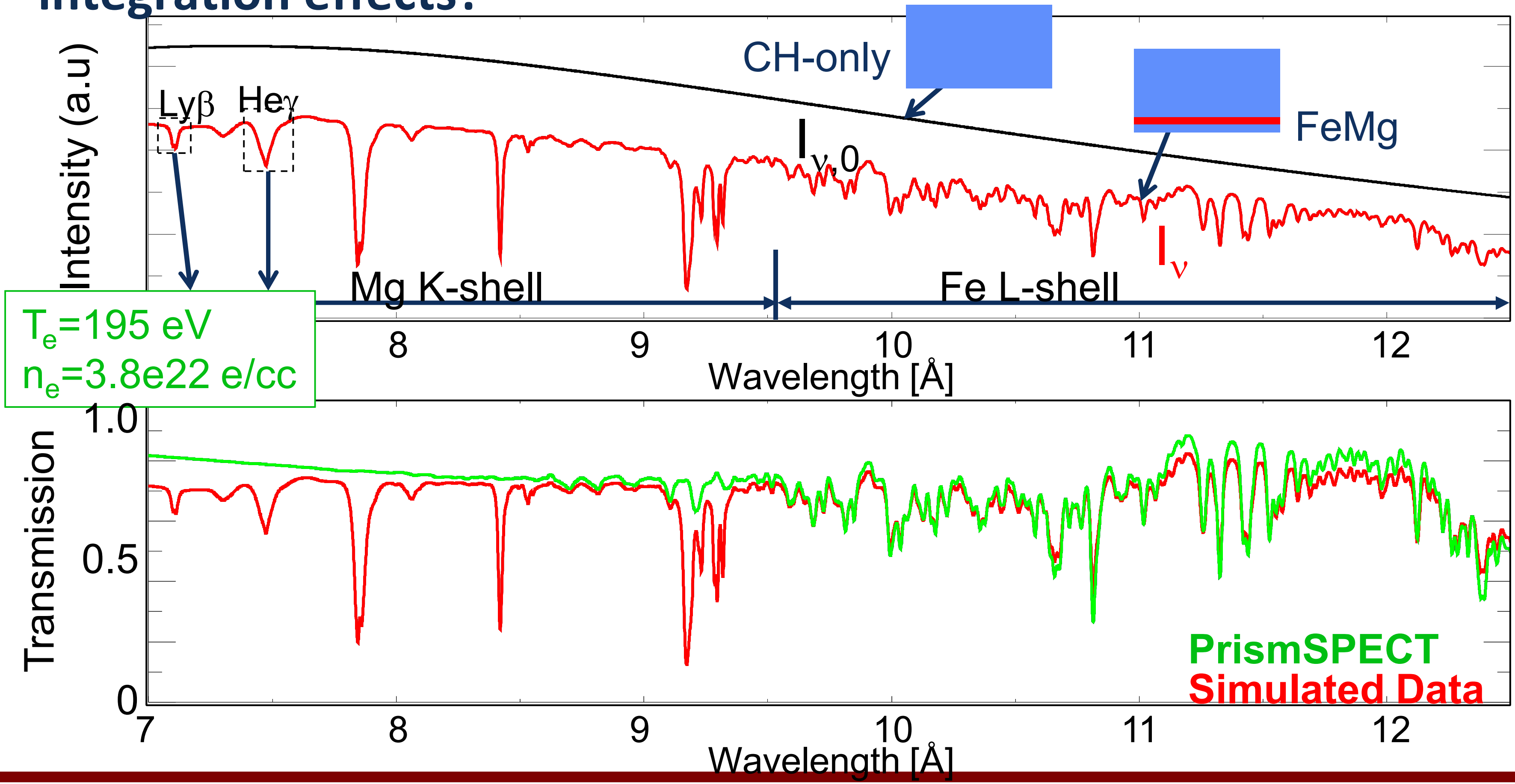

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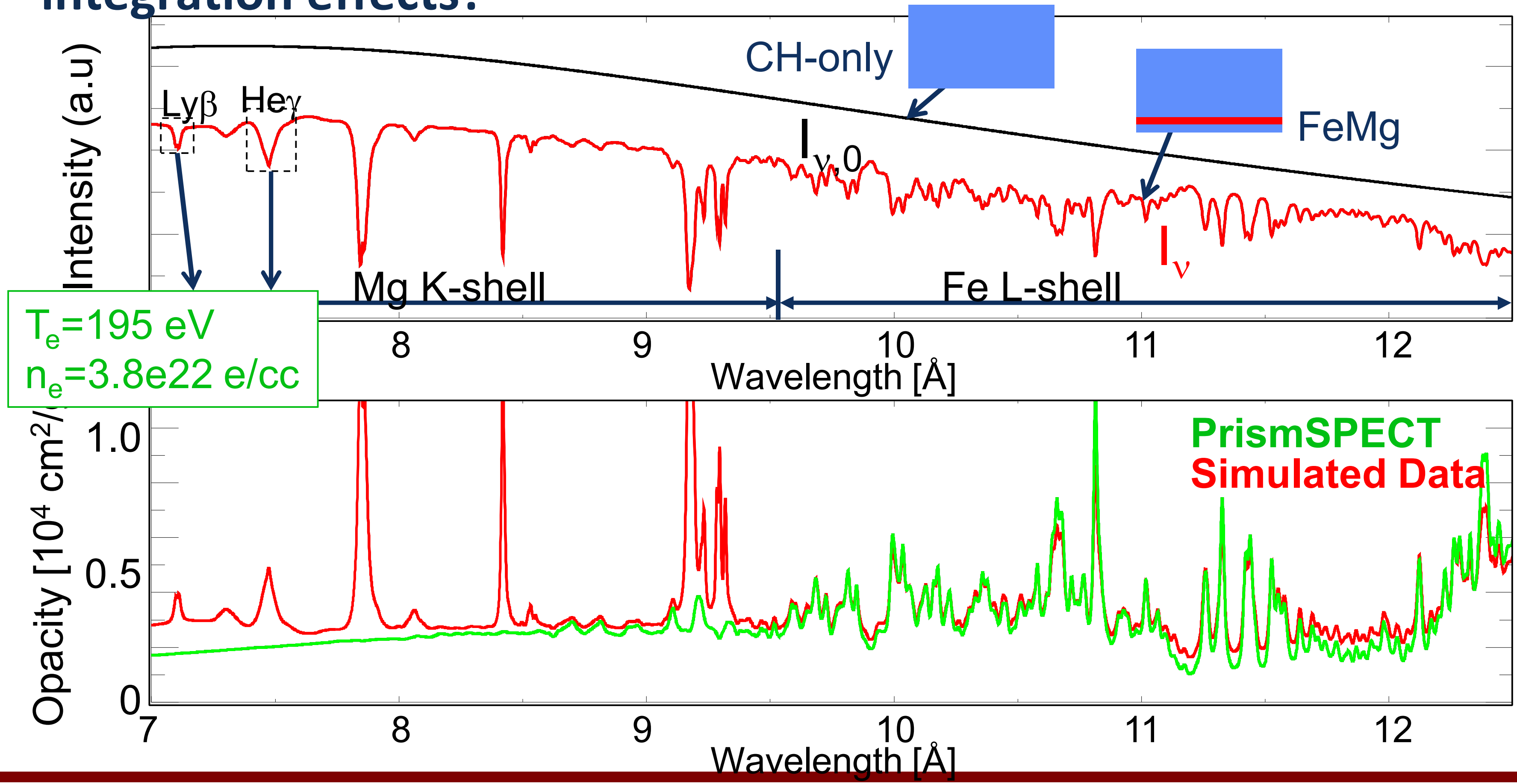

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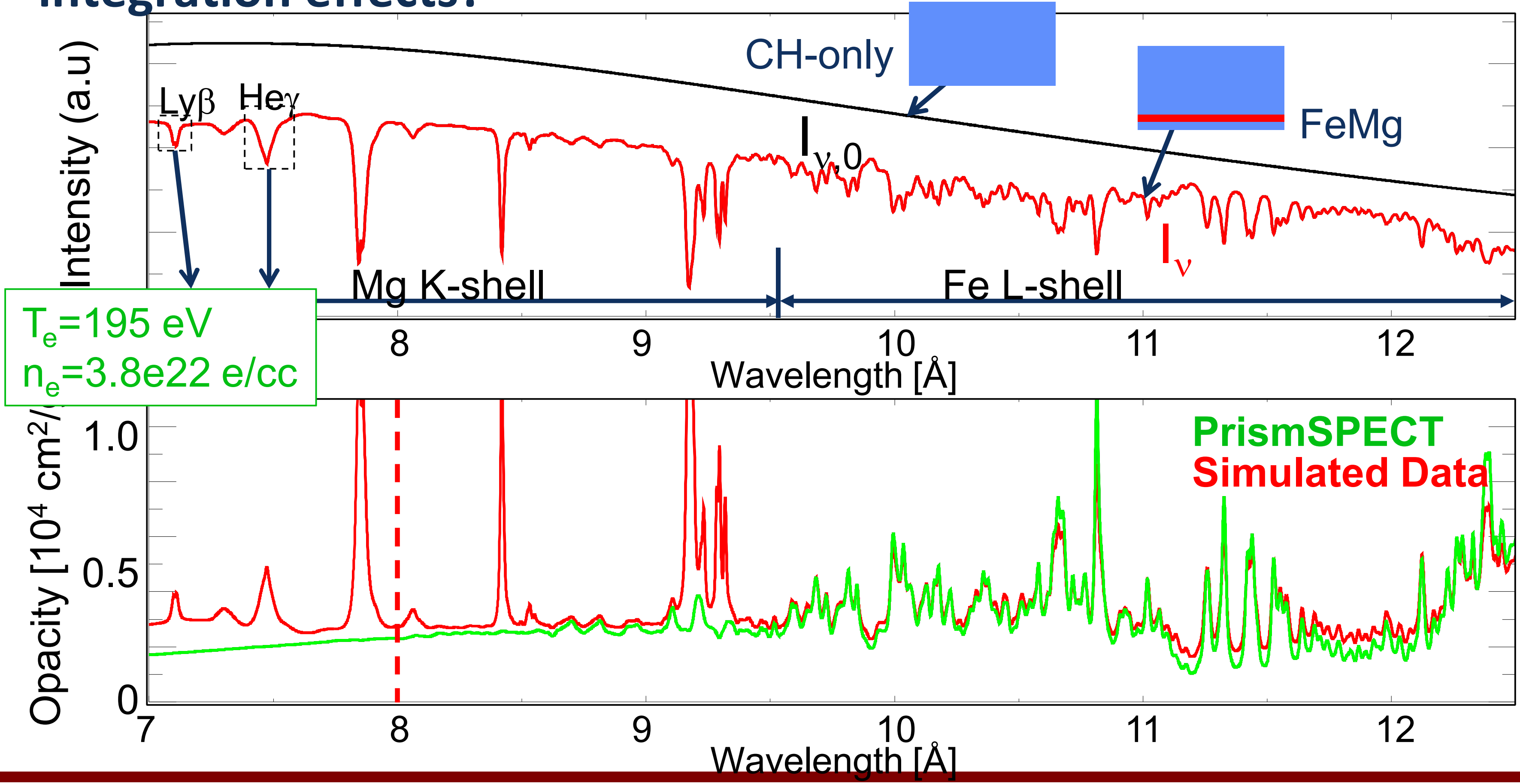

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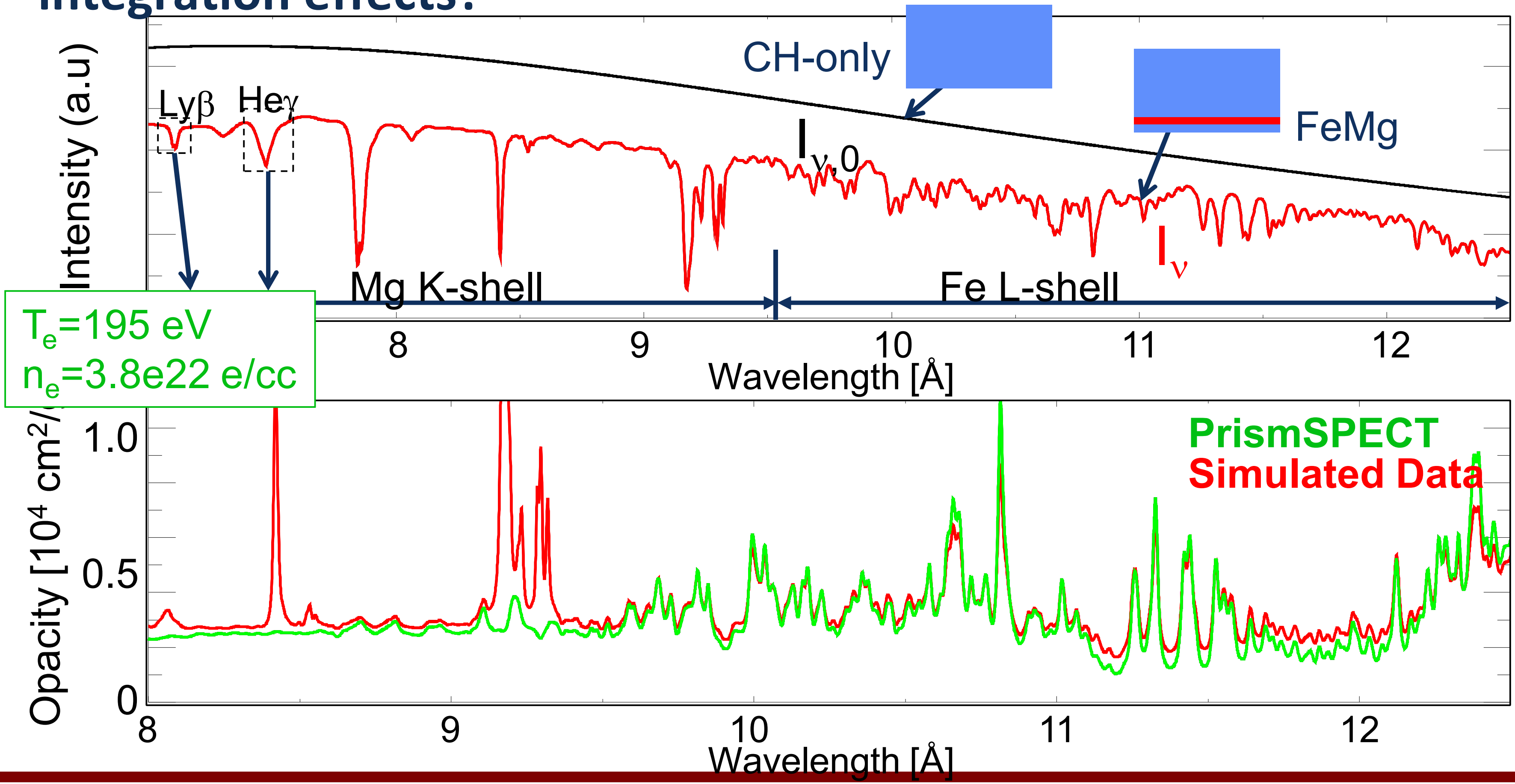

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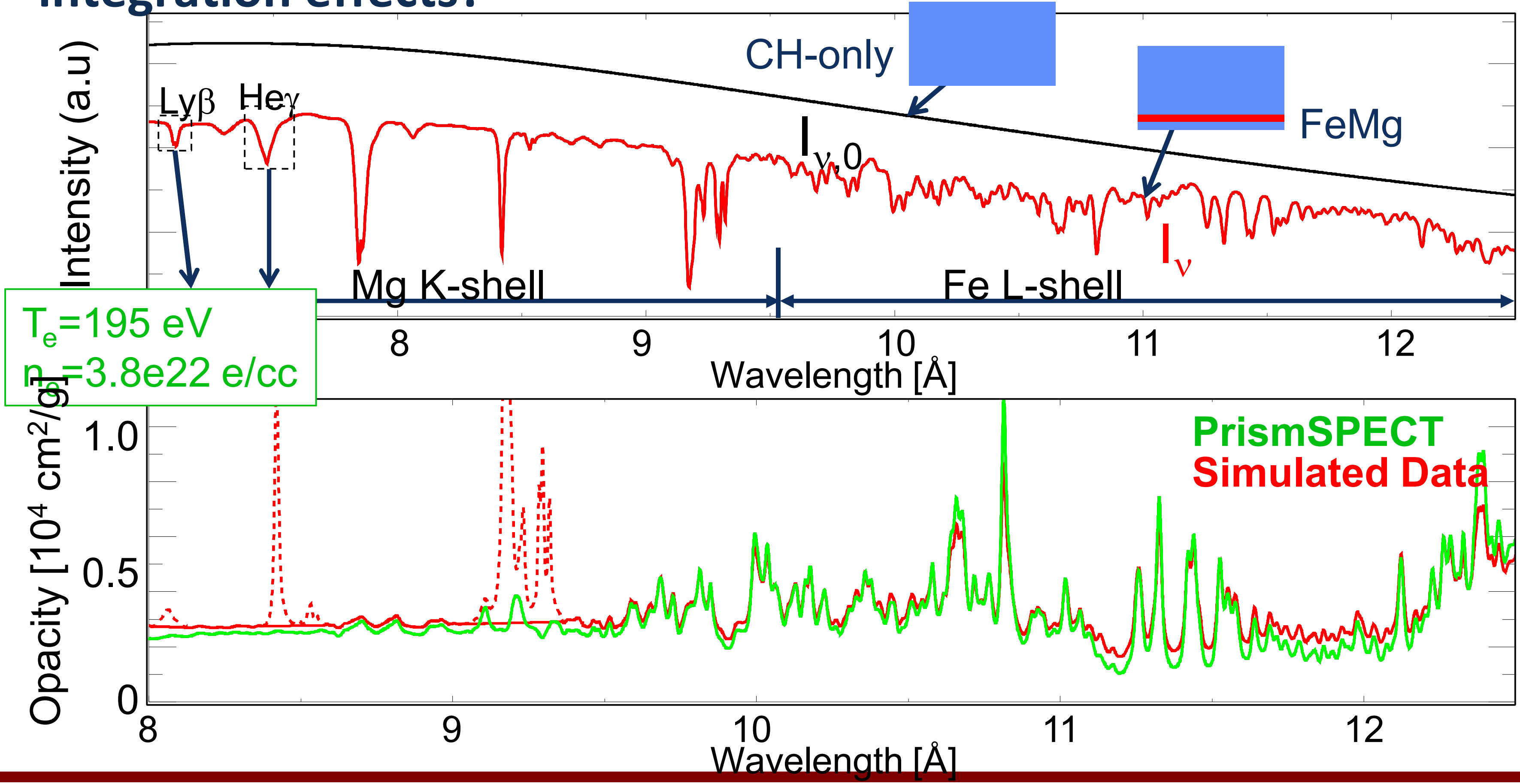

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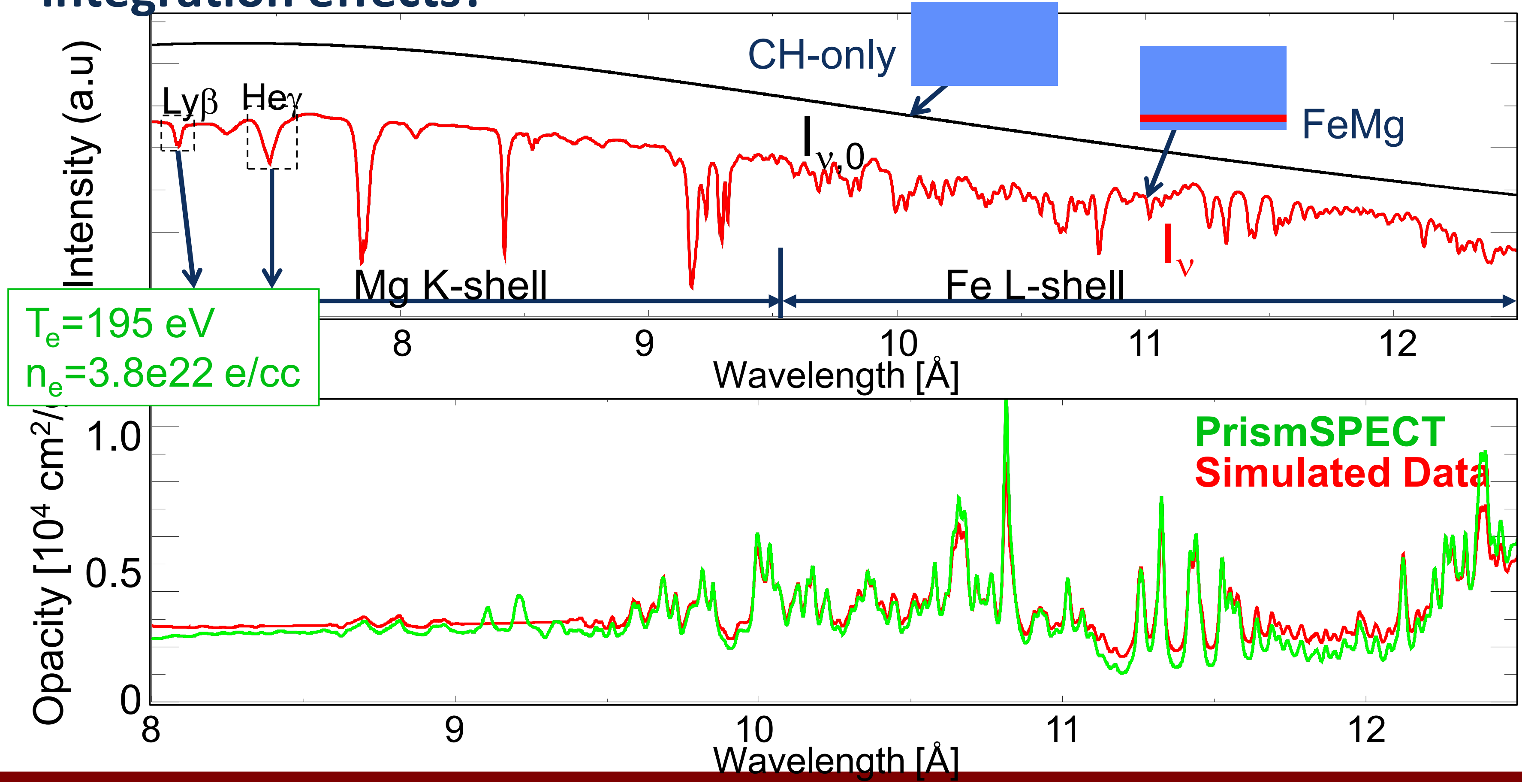
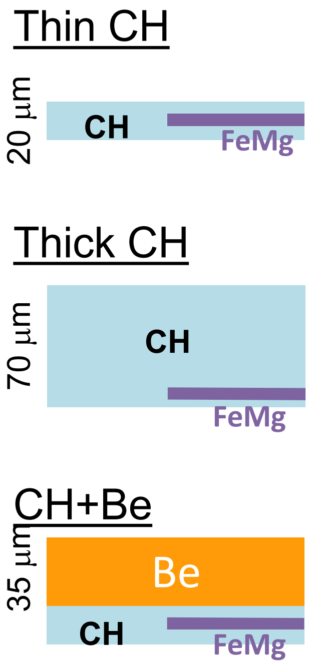
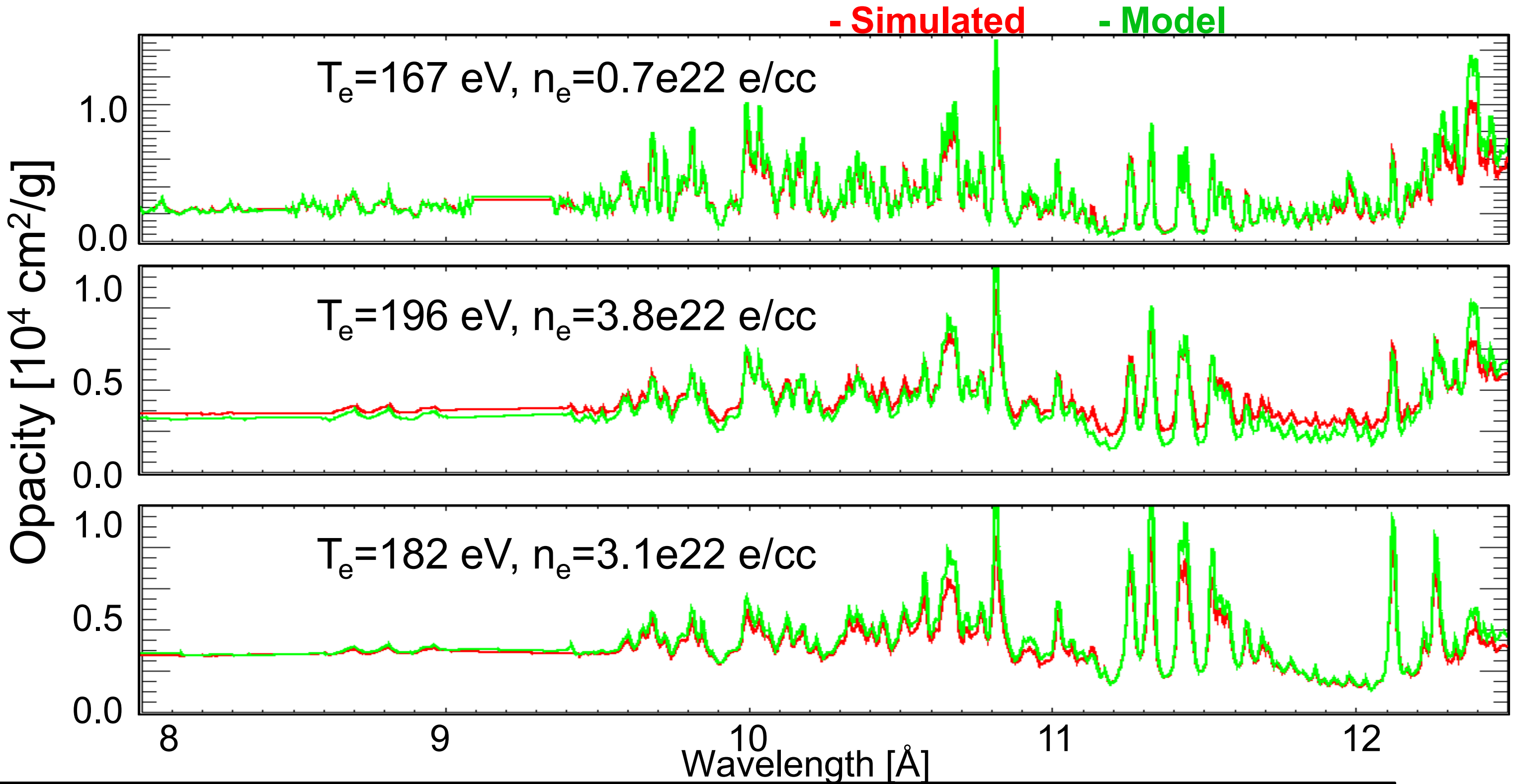


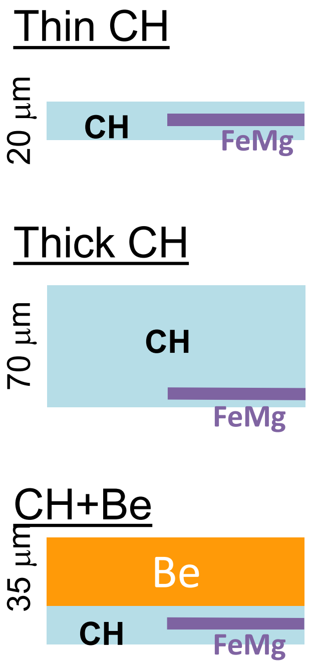
Investigated concerns do not explain the observed discrepancies

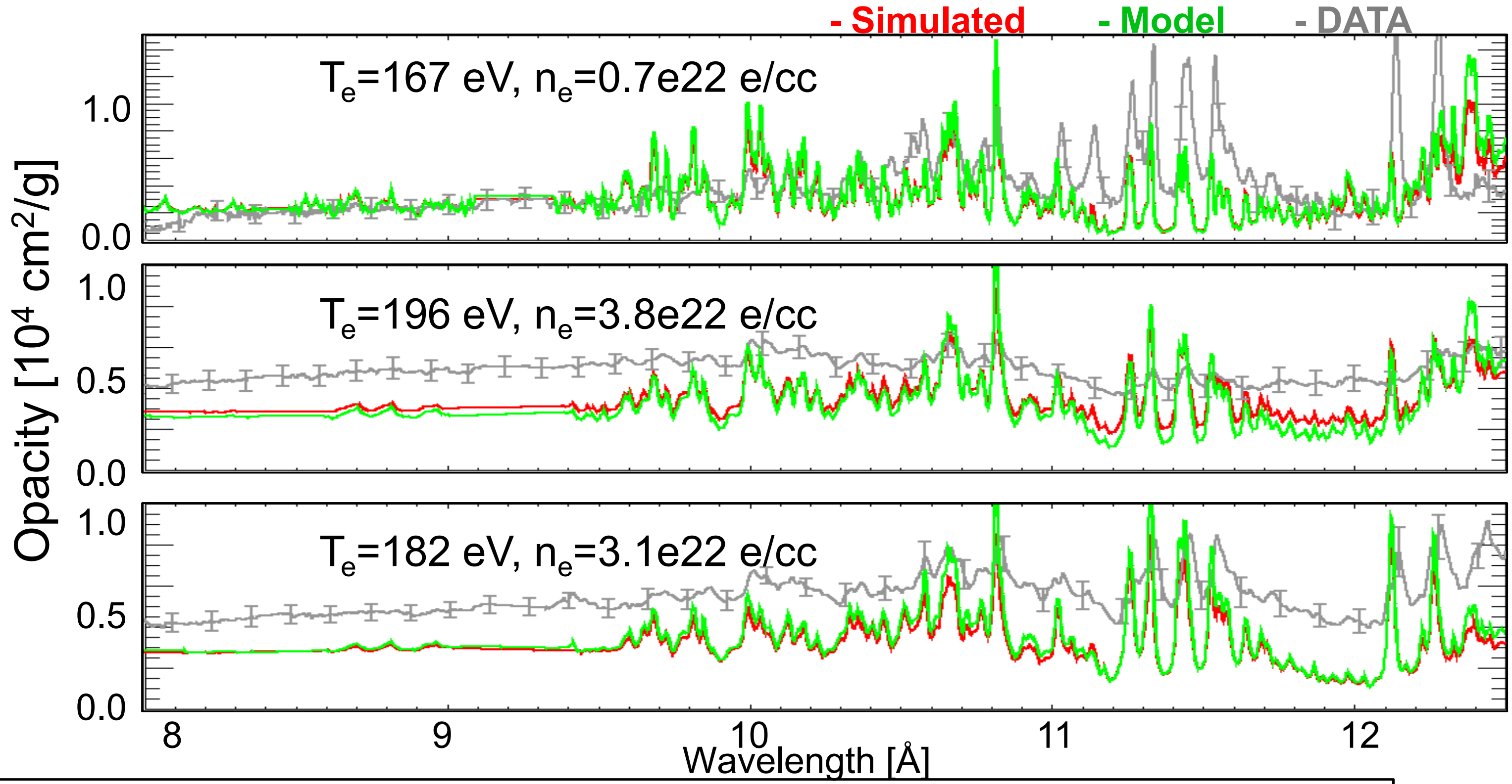




Self-emission effects, tamper effects, and time- and space-integration effects do not explain the observed discrepancies

Investigated concerns do not explain the observed discrepancies





Self-emission effects, tamper effects, and time- and space-integration effects do not explain the observed discrepancies